STATE OF ILLINOIS
DWIGHT H. GREEN, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
FRANK G. THOMPSON, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS — No. 100

ILLINOIS CLAYS AND SHALES AS MORTAR MIX

BY

R. K. HURSH, J. E. LAMAR AND R. E. GRIM

IN COOPERATION WITH
DEPARTMENT OF CERAMIC ENGINEERING, UNIVERSITY OF ILLINOIS

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1944

STATE OF ILLINOIS
DWIGHT H. GREEN, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
FRANK G. THOMPSON, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS — No. 100

ILLINOIS CLAYS AND SHALES AS MORTAR MIX

BY

R. K. HURSH, J. E. LAMAR AND R. E. GRIM

IN COOPERATION WITH
DEPARTMENT OF CERAMIC ENGINEERING, UNIVERSITY OF ILLINOIS

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1944

ORGANIZATION

STATE OF ILLINOIS
HON. DWIGHT H. GREEN, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
HON. FRANK G. THOMPSON, *Director*

BOARD OF NATURAL RESOURCES AND CONSERVATION

HON. FRANK G. THOMPSON, *Chairman*
NORMAN L. BOWEN, PH.D., D.SC., LL.D., *Geology*
ROGER ADAMS, PH.D., D.SC., *Chemistry*
LOUIS R. HOWSON, C.E., *Engineering*
WILLIAM TRELEASE, D.SC., LL.D., *Biology*
EZRA JACOB KRAUS, PH.D., D.SC., *Forestry*
ARTHUR CUTTS WILLARD, D.ENGR., LL.D.
President of the University of Illinois

GEOLOGICAL SURVEY DIVISION

M. M. LEIGHTON, *Chief*

SCIENTIFIC AND TECHNICAL STAFF OF THE

STATE GEOLOGICAL SURVEY DIVISION

100 Natural Resources Building, Urbana

M. M. LEIGHTON, PH.D., *Chief*
ENID TOWNLEY, M.S., *Assistant to the Chief*
VELDA A. MILLARD, *Junior Asst. to the Chief*
HELEN E. MCMORRIS, *Secretary to the Chief*
BETTY J. WESTERBEEK, *Geological Assistant*

GEOLOGICAL RESOURCES

Coal

G. H. CADY, PH.D., *Senior Geologist and Head*
L. C. MCCABE, PH.D., *Geologist* (on leave)
R. J. HELFINSTINE, M.S., *Mech. Engineer*
CHARLES C. BOLEY, M.S., *Assoc. Mining Eng.*
HEINZ A. LOWENSTAM, PH.D., *Assoc. Geologist*
BRYAN PARKS, M.S., *Asst. Geologist*
EARLE F. TAYLOR, M.S., *Asst. Geologist* (on leave)
RALPH F. STRETE, A.M., *Asst. Geologist*
M. W. PULLEN, JR., M.S., *Asst. Geologist*
ROBERT M. KOSANKE, M.A., *Asst. Geologist*
ROBERT ELLINGWOOD, B.S., *Asst. Geologist*
ARNOLD EDDINGS, B.A., *Research Assistant* (on leave)
HENRY L. SMITH, A.B., *Asst. Geologist*
RAYMOND SIEVER, B.S., *Research Assistant* (on leave)
JOHN A. HARRISON, B.S., *Research Assistant* (on leave)
MARY E. BARNES, B.S., *Research Assistant*
MARGARET PARKER, B.S., *Research Assistant*
ELIZABETH LOHMANN, B.F.A., *Technical Assistant*

Industrial Minerals

J. E. LAMAR, B.S., *Geologist and Head*
H. B. WILLMAN, PH.D., *Geologist*
ROBERT M. GROGAN, PH.D., *Assoc. Geologist*
ROBERT T. ANDERSON, M.A., *Asst. Physicist*
ROBERT R. REYNOLDS, M.S., *Asst. Geologist*
MARGARET COPELAND, A.B., *Asst. Geologist*

Oil and Gas

A. H. BELL, PH.D., *Geologist and Head*
CARL A. BAYS, PH.D., *Geologist and Engineer*
FREDERICK SQUIRES, B.S., *Petroleum Engineer*
STEWART FOLK, M.S., *Assoc. Geologist* (on leave)
ERNEST P. DUBOIS, PH.D., *Assoc. Geologist*
DAVID H. SWANN, PH.D., *Assoc. Geologist*
PAUL G. LUCKHARDT, M.S., *Asst. Geologis* (on leave)
WAYNE F. MEENTS, *Asst. Geologist*
JAMES S. YOLTON, M.S., *Asst. Geologist*
MARGARET SANDS, B.S., *Research Assistant*

Areal and Engineering Geology

GEORGE E. EKBLAW, PH.D., *Geologist and Head*
RICHARD F. FISHER, M.S., *Asst. Geologist*

Subsurface Geology

L. E. WORKMAN, M.S., *Geologist and Head*
CARL A. BAYS, PH.D., *Geologist and Engineer*
ROBERT R. STORM, A.B., *Assoc. Geologist*
ARNOLD C. MASON, B.S., *Assoc. Geologist* (on leave)
C. LELAND HORBERG, PH.D., *Assoc. Geologist*
FRANK E. TIPPIE, B.S., *Asst. Geologist*
MERLYN B. BUHLE, M.S., *Asst. Geologist*
PAUL HERBERT, JR., B.S., *Asst. Geologist*
CHARLES G. JOHNSON, A.B., *Asst. Geologist* (on leave)
DOROTHY B. SPEZIALE, M.S., *Asst. Geologist*
MARVIN P. MEYER, B.S., *Asst. Geologist*
MARGARET CASTLE, *Asst. Geologic Draftsman*
RUTH E. ROTH, B.S., *Research Assistant*

Stratigraphy and Paleontology

J. MARVIN WELLER, PH.D., *Geologist and Head*
CHALMER L. COOPER, M.S., *Assoc. Geologist*

Petrography

RALPH E. GRIM, PH.D., *Petrographer*
RICHARDS A. ROWLAND, PH.D., *Asst. Petrographer* (on leave)

Physics

R. J. PIERSOL, PH.D., *Physicist*
B. J. GREENWOOD, B.S., *Mech. Engineer*
DONALD O. HOLLAND, M.S., *Asst. Physicist* (on leave)

GEOCHEMISTRY

FRANK H. REED, PH.D., *Chief Chemist*
H. W. JACKMAN, M.S.E., *Chemical Engineer*
P. W. HENLINE, M.S., *Assoc. Chemical Engineer*
JAMES C. MCCULLOUGH, *Research Associate*
JAMES H. HANES, B.S., *Research Assistant*
LEROY S. MILLER, B.S., *Research Assistant*
ELIZABETH ROSS MILLS, M.S., *Research Assistant*

Coal

G. R. YOHE, PH.D., *Chemist*
HERMAN S. LEVINE, B.S., *Research Assistant*

Industrial Minerals

J. S. MACHIN, PH.D., *Chemist and Head*
DELBERT L. HANNA, A.M., *Asst. Chemist*

Fluorspar

G. C. FINGER, PH.D., *Chemist*

X-ray and Spectrography

W. F. BRADLEY, PH.D., *Chemist*

Analytical

O. W. REES, PH.D., *Chemist and Head*
HOWARD S. CLARK, A.B., *Assoc. Chemist*
L. D. MCVICKER, B.S., *Chemist*
WILLIAM F. WAGNER, M.S., *Asst. Chemist*
CAMERON D. LEWIS, B.A., *Asst. Chemist*
HERBERT N. HAZELKORN, B.S., *Research Assistant*
WILLIAM T. ABEL, B.A., *Research Assistant*
MELVIN A. REBENSTORF, B.S., *Research Assistant*
MARIAN C. STOFFEL, B.S., *Research Assistant*

MINERAL ECONOMICS

W. H. VOSKUILL, PH.D., *Mineral Economist*
DOUGLAS F. STEVENS, M.E., *Research Associate*
ETHEL M. KING, *Research Assistant*

PUBLICATIONS AND RECORDS

GEORGE E. EKBLAW, PH.D., *Geologic Editor*
CHALMER L. COOPER, M.S., *Geologic Editor*
DOROTHY E. ROSE, B.S., *Technical Editor*
MEREDITH M. CALKINS, *Geologic Draftsman*
BEULAH FEATHERSTONE, B.F.A., *Asst. Geologic Draftsman*
WILLIS L. BUSCH, *Principal Technical Assistant*
PORTIA ALLYN SMITH, *Technical Files Clerk*
ROSEMARY METZGER, *Technical Assistant*
LESLIE D. VAUGHAN, *Asst. Photographer*

Consultants: *Ceramics*, CULLEN W. PARMELEE, M.S., D.Sc., *and* RALPH K. HURSH, B.S., *University of Illinois*
Mechanical Engineering, SEICHI KONZO, M.S., *University of Illinois*

Topographic Mapping in Cooperation with the United States Geological Survey.
This report is a Contribution of the Industrial Minerals Division.

Aug. 10, 1944

70315 2M 9-44

CONTENTS

TABLES

ILLUSTRATIONS

ILLINOIS CLAYS AND SHALES AS MORTAR MIX

BY

R. K. Hursh, J. E. Lamar, and R. E. Grim

INTRODUCTION

The investigation of Illinois clays and shales as mortar mix was undertaken by the Illinois State Geological Survey in cooperation with the Department of Ceramic Engineering of the University of Illinois at the request of the Illinois Clay Manufacturers' Association and of members of the Structural Clay Products Institute. The objective was to determine whether typical Illinois clays and shales are satisfactory as mortar mix materials. In planning the experimental work, determination of some of the physical and mineralogical characteristics of the clay materials was included in order to find out what effect these variables might have on the properties of mortars and to disclose what types of material might be used most advantageously for this purpose.

Samples of various clays and shales of the State were obtained from producers or collected from outcrops. Physical tests to determine their particle-size characterstics were made by R. M. Grogan under the direction of J. E. Lamar, Head of the Industrial Minerals Division. Mineralogical examinations were made by R. A. Rowland under the direction of R. E. Grim, Petrographer. The investigation of the properties of mortar mixtures in which these clay materials were incorporated was conducted in the laboratories of the Department of Cerimac Engineering by P. E. Buckles under the direction of R. K. Hursh, Professor of Ceramic Engineering, who is the senior author of this report.

PREVIOUS INVESTIGATIONS OF CLAY MORTAR MIX

By R. K. Hursh

The use of clay as a plasticizer in cement-mortars was reported as early as 1884 and 1888. Examples of mortars that contain clay and that have shown excellent strength and weather resistance for periods of 25 or more years are known.

A number of experimental studies have been made on the properties of mortars that contain clay materials. Grant[1] reported in 1891 that a 10 per cent clay impurity in sand was not detrimental to the mortar strength. Davis and Troxell[2] studied the volumetric changes in Portland cement mortars with additions of lime hydrate and of clay. The contraction of the clay-cement mortar after 375 days in air was somewhat greater than that of the lime-cement mortar mixed in the same proportions. Tests of expansion of masonry piers laid up with the various mortars showed a somewhat smaller change in those containing clay than in the lime-cement or the plain cement mortars.

Spangler[3] found that clay could be used in the same proportion as hydrated lime in cement mortars without appreciable difference in strength, especially in the range up to a 30 per cent replacement of cement by clay. In a further comparison of lime hydrate and clay as replacements up to 50 per cent by volume for cement in 1:3 mortars, Spangler[4] showed that the clay additions produced mortars at least as strong and durable as those containing the lime. The tests also emphasized the necessity of restricting the amount of admixture to the minimum which will produce a workable mix.

Parsons[5] substituted 10 per cent by volume of clay for cement or 7½ per cent by volume for the fine aggregate in mortars, and studied the effects on the compressive strength, absorption, and permeability of the concrete. Replacement of 10 per cent of cement by clay caused 0 to 10 per cent decrease in compressive strength at ages over three months but did not appreciably affect permeability. Substitution of clay for 7½ per cent of fine aggregate increased compressive strength 0 to 37 per cent. The use of clay in both cases caused a slight increase in absorption in specimens stored out-of-doors but not in those that were frozen and thawed. Clay admixtures had no apparent effect on resistance to freezing and thawing.

Straight[6] states that clay gave better results than lime for 25 per cent replacements of the cement in 1:3 mortars in respect to strength, adhesion, bond, water penetration, and freezing. Among the advantages listed for the use of clay, he says, "it does not burn or bleach mortar colors; it gives better adhesion and suction and is therefore desirable for hollow-tile work; it seals pores and holds moisture that the mortar needs for setting and development of strength; suitable plasticity is obtained with a less amount of clay than of lime." In another article Straight[7] proposes standard specifications for the ground clay mortar mix and tests for the mortars in which it is used.

Palmer and Parsons[8] found that air-floated shale added the necessary plasticity and a high water-retaining capacity to mortars and allowed them to develop a maximum extent of bond without being dried out by porous bricks.

Withey and Wendt[9] conducted tests on mortars made with lime hydrates, with powdered clays, and a masonry cement. Different methods of curing were used. The clay-cement mixtures were somewhat

[1] Grant, W. H., Notes on cements, mortars and concrete: Trans. A.S.C.E. vol. 25, p. 498, 1891.
[2] Davis, R. E., and Troxell, G. E., Volumetric changes in Portland cement mortars and concrete: Am. Concr. Inst. vol. 25, p. 210, 1929.
[3] Spangler, M. G., Ground clay as a plasticizing agent: Jour. Am. Ceramic Society, vol. 13, p. 927, 1930.
[4] Spangler, M. G., Strength and durability tests of mortar mix mortar: Jour. Am. Ceramic Society, vol. 16, p. 246, 1934.
[5] Parsons, D. A., Clay in concrete: Bureau of Standards Jour. Res. R. P. 529, 10, 257, 1933.
[6] Straight, H. R., Clay manufacturers find a new market using waste clay for mortar mix: Brick and Clay Record, vol. 85, No. 2, p. 51, 1934.
[7] Straight, H. R., Mortar mix from waste clay proves practical in application: Brick and Clay Record, vol. 85, No. 3, p. 94, 1934.
[8] Palmer, L. A., and Parsons, D. A., Properties of mortar and bricks in relation to bond: Bureau of Standards Jour. Res. R. P. 683, pp. 12, 609, 1934.
[9] Withey, M. O., and Wendt, K. F., Tests of mortars for reinforced brick masonry: Tech. Paper Proc. A.S.T.M. Pt. II., p. 426, 1935.

less workable, exhibited lower expansions under moist curing, and showed somewhat greater contraction under air curing than the lime-cement mortars. Clay-cement mortars withstood freezing and thawing better than the lime-cement mortars of equal cement content. All of the clay-cement mortars passed the autoclave test in a satisfactory manner. The authors conclude that mortars of 1:4 cement and sand by weight with 25 to 33 per cent of hydrated lime or 20 to 25 per cent of very finely ground clay are sufficiently workable and strong for most reinforced brick masonry under moderate exposures. Where high strength is wanted or where exposure is severe, 1:2½ mortar with 25 to 33 per cent of lime hydrate or a 1:3 mortar with 17 to 25 per cent of clay is tentatively recommended.

Collin[10] found that suitable clays and shales could replace lime in equal proportions in cement mortars. Tests of consistency, strength and plasticity showed a maximum permissible replacement of 25 to 35 per cent of cement.

Anderegg[11] states that finely ground shales give good results in mortars and that fireclay added in amounts up to 25 per cent gave extremely weather resistant mortar. Shale does not contribute the flexibility to the mortar that lime does but it may reduce shrinkage. Argillaceous materials have an advantage over calcareous materials in giving mortars with a low creep, which is essential in reinforced construction.

Dodd[12] compared mortars made with mortar mix (ground clay) with those containing lime additions in the proportions of 2 cement:1 lime or mortar mix:8 sand. The mortars containing clay showed greater tensile, compressive, and bond strengths, shorter setting time, greater plasticity, and less efflorescence than did those containing lime.

Schurecht and Corbman[13] have made the most extensive investigation of the use of clay materials as plasticizing agents in cement mortars. Tests were made with various shales and surface clays from New York and with one mortar mix clay from Iowa. Two masonry cements and a series of lime hydrates were also used for comparison. The clays were ground to such fineness that 80 per cent passed 100-mesh. Wet screen tests showed 73 to 98 per cent passing 200-mesh.

The compressive, tensile, and bond strength of clay-cement mortars tested by the above writers was somewhat higher than that of lime-cement mixtures. Mortars containing 10 and 25 per cent of plasticizer showed some loss of strength but were in good condition after 30 cycles of freezing and thawing. Mortars containing clays were more resistant than those with equivalent amounts of lime. Although the percentage loss of strength of clay mixtures was a little greater than that of the lime mixtures, the actual strength after freezing tests was equal to or greater than that of the lime-cement mortars. Shrinkage of the clay-cement mortars during storage was less than that of lime-cement mixtures when the same proportions by weight were used. With equal proportions by volume, the shrinkage of the clay mortars was greater but their higher strength would permit using a larger proportion of sand. Equal or lower shrinkage could thus be obtained. Water retention of clay-cement mortars was generally higher than of lime-cement mortars when compared on an equivalent bond strength basis.

Good results were obtained with a mixture in the proportions by volume of 0.25 clay, 0.75 sand and 3.0 cement on all of the clays tested.

---

10 Collin, L. P., Clay as a plasticizer in masonry mortars: Jour. Canadian Ceramic Society, vol. 5, p. 35, 1936.
11 Anderegg, F. O., Mortar properties improved by adding mortar mix: Brick and Clay Record, vol. 90, p. 280, 1937.
12 Dodd, C. M., Report on mortar mix: May 23, 1938.
13 Schurecht, H. G., and Corbman, M., The use of New York clays in masonry mortars: New York State College of Ceramics, Ceramic Exp. Sta., Bull. 1, Dec. 1937.

SAMPLES

By J. E. Lamar

SAMPLING

The samples for this investigation were selected on the premise that the materials studied should include:

(1) Samples representative of the various kinds of shales, underclays, and surface clays now used in Illinois for the manufacture of clay products.

(2) Samples of shales, clays, or other materials, not used for making clay products, which are of interest because of their mineral composition or texture.

(3) Samples giving a reasonably complete representation of the kinds of clay minerals found in Illinois clays and shales as well as the amounts of clay minerals and the various combinations in which they occur.

(4) Samples giving a reasonably complete representation of the various ranges in particle-size distribution existing in the clays and shales of Illinois.

By selecting samples on the above basis, it was believed that practically all types of clays and shales occurring in Illinois would be represented and that the data resulting from the testing of these samples could be interpreted to evaluate the suitability for mortar mix of the bulk of the individual clay and shale deposits of the State.

It was also felt that samples chosen as indicated above would provide a sound basis for determining the significance of particle-size distribution and clay-mineral composition in relation to the various important properties of the mortars in which clay or shale mortar mixes are used.

With the foregoing factors in mind, 22 samples were selected for study (table 1). With the exception of the sample of gumbotil, all materials are in actual commercial use for the manufacture of clay products or other purposes. The samples included:

Ten samples of shale from sources well distributed throughout the State and covering a wide range in amount of clay-mineral material and in particle-size distribution or texture.

Three samples of underclays, or fireclays as they are sometimes known, of varied clay-mineral composition and texture.

Three samples of till, a pebbly, mostly limy, clay of glacial origin.

One sample of gumbotil, a non-limy clay occurring extensively in southern and western Illinois and resulting from the weathering of glacial till under conditions of poor drainage for a long period of time.

One sample of Illinois fuller's earth, used for decolorizing oils and for other purposes.

One sample of southern Illinois kaolin, a material very high in the clay mineral kaolinite.

One sample of "Coal Measures" clay having an unusual mineral composition.

One sample of loess, a wind transported and deposited material found extensively along the major rivers of western and southern Illinois.

One sample of crude southern Illinois tripoli, a material consisting almost exclusively of exceedingly minute quartz particles which occur singly or in aggregates of various sizes.

With a few exceptions samples consisted of 200 pounds of dried brick taken at random from dryer cars. It was felt that such samples would be reasonably representative of the raw materials in use and would be similar to the dryer waste which in some states is a major source of clay from which mortar mix is made. Samples 9, 10, 13, 15 and 16 were lump or coarsely crushed materials. The gumbotil sample, No. 16, was taken from an outcrop near Louisville, Illinois. A few of the shale samples contained small amounts of barium carbonate added to reduce scumming. When this situation existed an additional 200-pound sample of the barium-free shale in the storage bins was obtained so that both barium-free and barium-containing material would be available for study. For the most part, the samples were supplied direct by various clay manufacturers and producers.

TABLE 1.—SAMPLES TESTED

Sample No.	Kind of material	Source Part of Illinois	Geological age
0	Shale	Northern	"Coal Measures"—Francis Creek
1	Underclay	Northern	" " —"Pottsville"
2	Glacial till	Northeastern	Pleistocene—Wisconsin
3	" "	Northeastern	" — "
4	Shale	Northewstern	"Coal Measures"—Purington
5	"	Southwestern	" " —McLeansboro
6	"	Central	" " —Farmington
7	"	North Central	" " —Shale below No. 6 coal
8	"	Eastern	" " —Farmington
9	Fuller's earth	Southern	Eocene—Porters Creek
10	Kaolin	Southern	Cretaceous
11	Underclay	North Central	"Coal Measures"—"Pottsville"
12	Glacial till	Northeastern	Pleistocene—Wisconsin
13	Clay	Northern	"Coal Measures"—"Pottsville"
14	Underclay	Northern	" " — "
15	Crude tripoli	Southern	Devonian—Clear Creek
16	Gumbotil	Central	Pleistocene—Illinoian
17	Shale	Northern	"Coal Measures"—Shale over No. 6 coal
18	"	Southwestern	"Coal Measures"—Shale over Collinsville limestone
19	Loess	Southwestern	Pleistocene—Wisconsin
20	Shale	Southwestern	"Coal Measures"—Shoal Creek
21	"	Southwestern	" " — " "

PARTICLE SIZE OF SAMPLES

The particle size of a clay or shale is difficult to measure in absolute terms. The method employed to disperse the material, the violence of the method used, and the length of time during which a sample is subjected to a dispersing procedure will in a large measure influence the extent to which a shale or clay is broken down towards its ultimtae particle size. The present study makes no claims to have reached ultimate particle size, but the dispersion processes employed are believed to give results satisfactory for all practical purposes and to be at least as severe as any dispersing conditions likely to be encountered in actual use of clays or shales as mortar mix.

The purpose of the particle-size measurements of the raw materials studied in this investigation were two-fold, first to determine the effect of particle size on the quality of a clay or shale for mortar mix and, second, to ascertain whether particle size can be used as a means of distinguishing between suitable and unsuitable clays and shales. The data also have additional value because in connection with the mineralogical data they give some idea of the slaking character of the samples. Thus, a clay or shale which slakes readily in water should, under conditions of the particle-size determinations, break down so that most or all of the clay mineral material which it contains would be finer than 2 microns (0.002 millimeter). Comparison of the amounts of clay mineral material as shown by microscopic analysis with the amounts of minus 2 micron material indicated by the particle-size analyses gives an idea of slaking character.

METHOD OF ANALYSIS

Particle-size analyses were made by the "hydrometer" method using a Casagrande type hydrometer. This procedure has been investigated and described by a number of different writers and has been found reasonably accurate and rapid.[14] Briefly it con-

[14] Bouyoucos, G. J., Hydrometer method for making a very detailed mechanical analysis of soils: Soil Science, vol. 26, pp. 233-38, 1928; (b) Hydrometer method in the study of soils; op. cit., vol. 25, pp. 365-69, 1928; (c) Hydrometer method for making a mechanical analysis of soils; Bull. Am. Ceramic Soc., vol. 14, No. 8, pp. 259-62, 1935.

Thoreen, R. C., Comments on hydrometer method of mechanical analysis: Public Roads, vol. 14, No. 6, pp. 93-105, 1933.

Casagrande, A., Hydrometer method for determination of fineness, distribution of soils. Julius Springer, Berlin, 1934.

Willis, E. A., and Johnston, C. M., Mechanical analysis of Portland cement by the hydrometer method: Public Roads, vol. 15, pp. 76-78, May 1934.

Biddle, S. B., Jr., and Klein, A., Hydrometer method for determining fineness of Portland-Puzzolan cement: Proc. A.S.T.M., vol. 36 (Part II), pp. 310-22, 1936; Ceramic Abs., vol. 16, No. 6, p. 181, 1937. (Con'd. on p. 13.)

sists of measuring, by means of a hydrometer, the amount of a sample of known weight which remains in an aqueous suspension after certain stated periods of time, and from these data constructing a curve of particle-size distribution.

As a rule, dispersion of samples preparatory to hydrometer analysis is done by means of a malted milk stirrer. In the present tests, which involved a number of moderately well indurated shales, a dispersion procedure believed to be somewhat more thorough was employed. Five-pound representative fractions were taken of the "coarse-ground" materials that had been prepared for use in the strength tests by grinding the raw materials to pass roughly an 8-mesh sieve. Each of these fractions was thoroughly mixed and quartered until a sample of about 200 grams resulted. This 200-gram sample was dried for four hours at 110°C., and then shaken dry for an hour in a mechanical mixer to insure thorough mixing.

Optimum deflocculation was determined for each sample as follows: Six 100 cc. bottles were numbered from 1 to 6. In each bottle 5 grams of the 200-gram sample were placed. The bottles were half filled with distilled water. In the first bottle no deflocculating agent was introduced but into each succeeding bottle increasing amounts of ¼ normal sodium oxalate solution were added, respectively, 1, 2, 3, 4, 8 and 16 cc. of the solution. The bottles were then filled to about 75 cc. with distilled water and shaken mechanically for three hours, after which they were allowed to stand for 24 hours. That bottle in which there was the highest and densest column of suspended material was considered to indicate optimum deflocculation, and from the amount of electrolyte used therein for 5 grams of clay the amount of sodium oxalate required to give optimum deflocculation for 50 grams of the clay or shale sample was calculated. In case optimum deflocculation was not clearly shown by the six bottles, additional similar tests were made with different amounts of sodium oxalate until an optimum was evident.

[14] Con't.
Norton, F. H., and Speil, S., Measurement of particle sizes: Jour. Am. Ceramic Soc., vol. 21, No. 3, pp. 89-97, 1938.
Reimers, J. C., Application of the hydrometer method of fineness analysis to porcelain enamel slips: Preprint, 41st Ann. Meeting, Am. Ceramic Soc., April 16-22, 1939.

Fifty-gram portions of the 200-gram sample mentioned above were used for the hydrometer tests. Each portion was soaked for 20 hours in distilled water in a fruit jar, the proper amount of sodium oxalate for optimum deflocculation was added, and the sample was shaken mechanically for four hours in an end-over-end shaker operating at 48 r.p.m. After shaking, the sample was transferred to a 270-mesh sieve (opening 0.053 mm.) and washed. The material passing the sieve was returned to the jar; the material caught on the sieve was transferred to a porcelain mortar and gently rubbed with a rubber tipped pestle. The material in the mortar was then washed into the sieve again and the material which did not pass the sieve was returned to the mortar for further rubbing. This process was repeated until all aggregates and lumps of clay or shale in the sample were broken down and the material retained on the sieve consisted only of discrete sand grains, rock fragments, brick fragments and the like.

After the sieving procedure, all of the sample was placed in the fruit jar and subjected to four additional cycles of 20 hours soaking and four hours shaking, giving a total of 100 hours soaking and 20 hours shaking.

From the fruit jars the samples were transferred to 1000 cc. graduated cylinders for hydrometer analysis. These tests were made with the cylinders immersed in a constant temperature bath at 67°F. Hydrometer readings were taken at intervals of 10 minutes, 30 minutes, and 1, 2, 4, 8, 24, and 48 hours. After the hydrometer analyses were completed, the +270-mesh material was recovered by wet screening and was dried and weighed. The character of this portion of the sample was identified with the microscope. All samples were run in duplicate and close checks were obtained in all cases. The results of the analyses are the average of the results of the duplicate analyses.

Results of Tests

Results of the particle-size analysis are given in tables 2 and 3 and figures 1 and 2. The character of the material retained on a 270-mesh sieve is shown in table 4.

The data in tables 2 and 3 and figure 1 show a wide variety of particle-size distributions among the samples tested. The

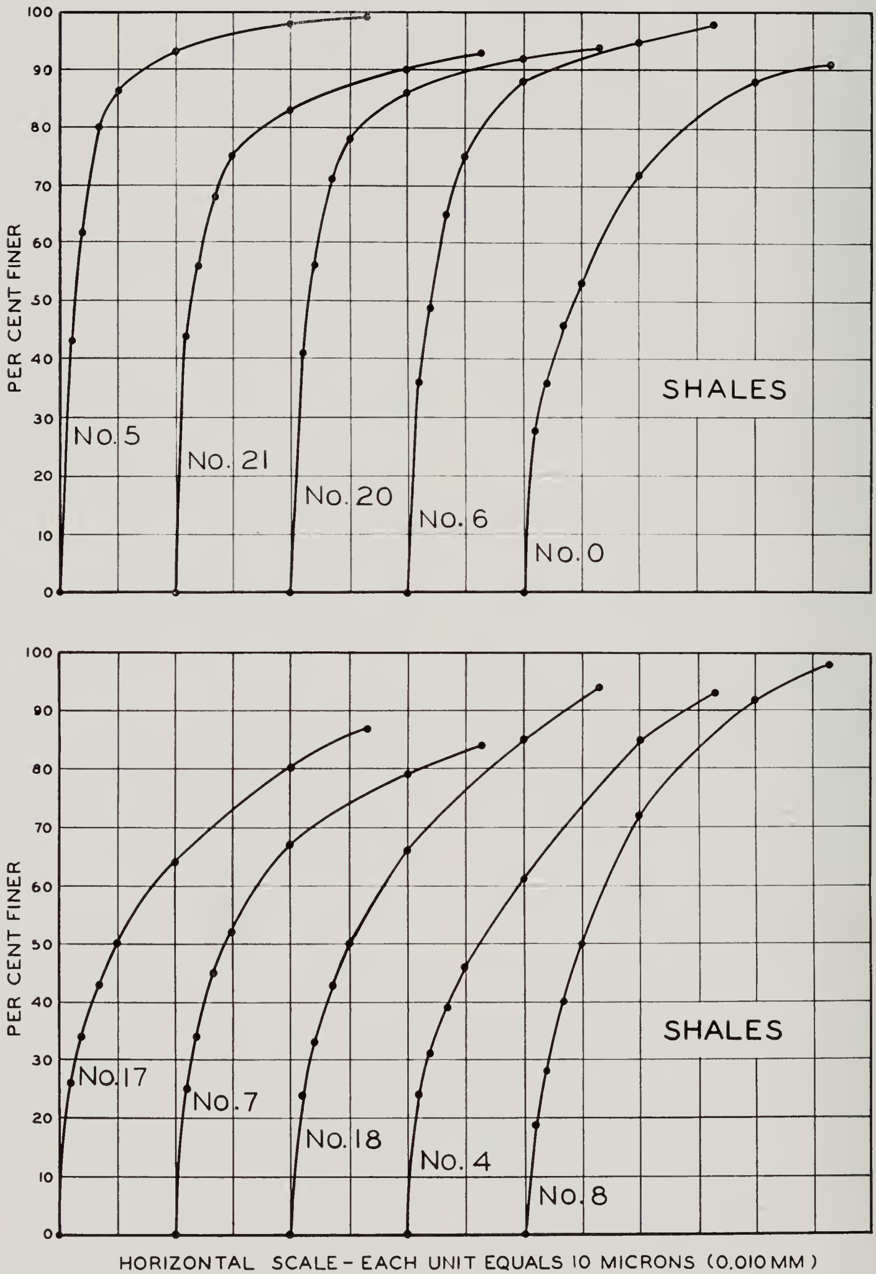

Fig. 1.—Graphs showing particle-size character of shale samples.

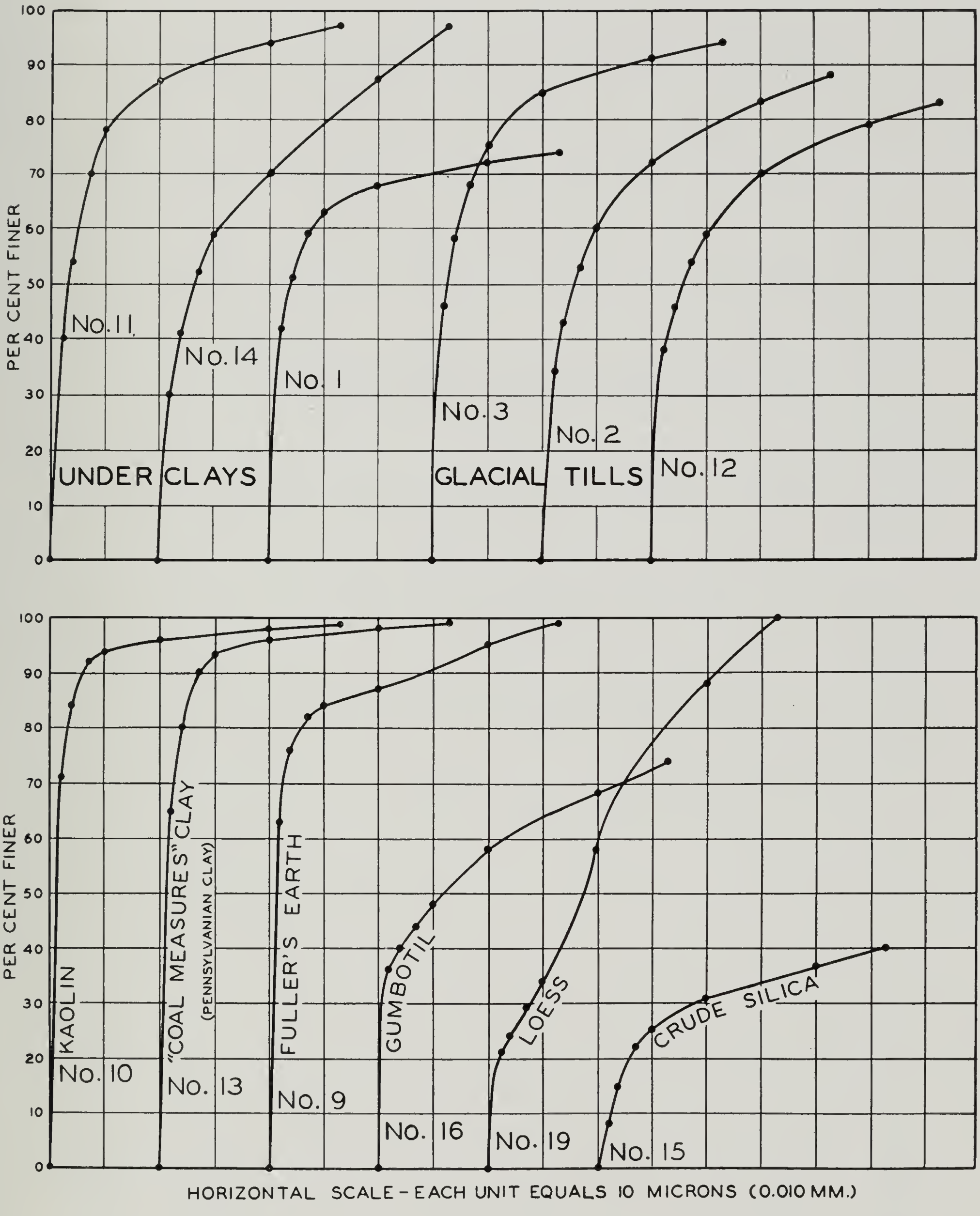

FIG. 2.—Graphs showing particle-size character of underclays, tills, and other samples studied.

Table 2.—Particle-Size Distribution of Samples According to Size Grades

Sample No.	Kind of material	Per cent of sample between given sizes in microns[a]								
		–2	2–4	4–7	7–10	10–20	20–40	40–53	53–246 (270–60 mesh)	+246 (60 mesh)
0	Shale	28	8	10	7	19	16	3	2	7
4	"	24	7	8	7	15	24	8	5	2
5	"	43	19	18	6	7	5	1	1	Trace [b]
6	Shale	36	13	16	10	13	7	3	1	1
7	"	25	9	11	7	15	12	5	10	6
8	"	19	9	12	10	22	20	6	2	Trace
17	Shale	26	8	9	7	14	16	7	12	1
18	"	24	9	10	7	16	19	9	5	1
20	" [c]	41	15	15	7	8	6	2	3	3
21	" [d]	44	12	12	7	8	7	3	5	2
1	Underclay	42	9	8	4	5	4	2	9	17
11	"	40	14	16	8	9	7	3	3	Trace
14	"	30	11	11	7	11	17	10	3	Trace
2	Glacial till	34	9	10	7	12	11	5	7	5
3	" "	46	12	10	7	10	6	3	3	3
12	" "	38	8	8	5	11	9	4	10	7
16	Gumbotil	36	4	4	4	10	10	6	16	10
9	Fuller's earth	63	13	6	2	3	8	4	1	Trace
10	Kaolin	71	13	8	2	2	2	1	1	Trace
13	Coal Measures clay	65	15	10	3	3	2	1	1	Trace
15	Crude silica	8	7	7	3	6	6	3	13	47
19	Loess	21	3	5	5	24	30	12	Trace	—

[a] 1 micron is 0.001 millimeter or 0.00004 inch.
[b] Less than 1 per cent.
[c] Mixed pit-run shale and clay.
[d] Mixed dryer waste and mine-run clay.

TABLE 3.—PARTICLE-SIZE DISTRIBUTION OF SAMPLES ACCORDING TO PERCENTAGE FINER THAN VARIOUS SIZES

Sample No.	Kind of material	Per cent finer than following sizes in microns[a]							
		2	4	7	10	20	40	53 (270-mesh)	246 (60-mesh)
0	Shale	28	36	46	53	72	88	91	93
4	"	24	31	39	46	61	85	93	98
5	"	43	62	80	86	93	98	99	100
6	Shale	36	49	65	75	88	95	98	99
7	"	25	34	45	52	67	79	84	94
8	"	19	28	40	50	72	92	98	100
17	Shale	26	34	43	50	64	80	87	99
18	"	24	33	43	50	66	85	94	99
20	" [b]	41	56	71	78	86	92	94	97
21	" [c]	44	56	68	75	83	90	93	98
1	Underclay	42	51	59	63	68	72	74	83
11	"	40	54	70	78	87	94	97	100
14	"	30	41	52	59	70	87	97	100
2	Glacial till	34	43	53	60	72	83	88	95
3	" "	46	58	68	75	85	91	94	97
12	" "	38	46	54	59	70	79	83	93
16	Gumbotil	36	40	44	48	58	68	74	90
9	Fuller's earth	63	76	82	84	87	95	99	100
10	Kaolin	71	84	92	94	96	98	99	100
13	"Coal Measures" clay	65	80	90	93	96	98	99	100
15	Crude silica	8	15	22	25	31	37	40	53
19	Loess	21	24	29	34	58	88	100	

[a] 1 micron is 0.001 millimeter or 0.00004 inch.
[b] Mixed pit-run shale and clay.
[c] Mixed dryer waste and mine-run clay.

TABLE 4.—MAJOR CONSTITUENTS OF SAND FRACTION[a]

	Sand coarser than 60-mesh											Sand finer than 60-mesh											
	Quartz	Siltstone	Ferruginous grains	Clay ironstone	Limestone and calcite	Pyrite	Black shale	Chert	Burned clay fragments	Coal	Cinders	Quartz	Siltstone	Ferruginous grains	Clay ironstone	Limestone and calcite	Pyrite	Black shale	Mica	Chert	Burned clay fragments	Coal	Cinders
Shale																							
0		x	x		x				x			x	x	x							x		
4	x	x	x					x			x	x	x	x					x				x
5	x			x		x					x	x		x	x				x				x
6	x	x		x			x		x			x	x					x					
7		x	x	x		x						x	x	x	x				x				
8	x	x			x	x					x	x	x				x						x
17	x	x							x	x	x	x	x			x			x			x	
18	x	x	x	x				x			x	x	x	x	x				x			x	x
20	x		x		x			x				x		x		x				x			
21	x	x		x	x			x			x	x		x	x	x							x
Underclay																							
1	x							x	x			x									x		
11	x	x				x				x		x	x		x		x					x	
14	x	x				x	x				x	x	x				x	x				x	x
Glacial till																							
2	x	x			x		x		x	x		x	x			x		x			x	x	
3	x	x			x		x					x	x			x		x					
12	x	x	x		x		x	x				x	x	x		x		x					
Gumbotil																							
16	x	x	x					x				x		x						x			
Miscellaneous																							
9		x	x										x	x					x				
10	x		x									x		x					x				
13	x		x			x	x	x		x	x	x		x			x	x		x		x	x
19												x							x				x
15	x										x	x											

[a] Siltstone is a rock composed of grains intermediate in size between fine sand and clay. Ferruginous grains are brown, yellow, or red and contain much iron oxide with little or no limy material. Clay ironstone is a gray or brown rock containing iron carbonate.

In addition to the constituents shown in the table, sample No. 12 contains abundant fragments of igneous rocks in the coarse fraction and brown, fossil spore-like bodies in the fine fraction. The fine portion of sample No. 19 contains numerous grains of feldspar, hornblende, and other minerals.

minus 2 micron fraction ranges from 8 to 71 per cent, the 10-20 micron fraction ranges from 2 to 24 per cent, and the material retained on a 270-mesh sieve ranges from a trace to 60 per cent. It is believed that the particle-size distribution of most Illinois materials likely to be used as mortar mix are represented or approximated by the samples tested.

Examination of figure 1 shows that the curves of particle-size distribution with a few exceptions fall into three groups. In the first group are those curves which rise nearly vertically to 70 per cent or above, such as the curves of samples 3, 5, 6, 9, 10, 11, 13, 20 and 21. This type of curve indicates a relatively high content of fine-sized particles. The second group of curves are those which have a roughly uniform curvature above the 20 per cent line and include Nos. 0, 2, 4, 7, 8, 12, 14, 17 and 18. Such curves signify a comparatively small amount of fine-sized particles and a comparatively uniform distribution of medium-sized and coarse particles. In the third group are curves 1, 15, 16 and 19, which are of various characters but all except No. 19 are distinguished by relatively large amounts of coarse particles.

Significance of Particle-Size Distribution Data

Comparison of the particle distribution data with the information on mineral composition indicates that the percentage of material finer than 4 microns is reasonably close to the estimated amount of clay mineral in samples 2, 3, 12, 16, 9, 10, 13, 15, 19 which include glacial till, gumbotil, and other unconsolidated materials mostly not part of the bedrock of the State.

The shales and underlays show no similar consistent relationship although the percentage of material finer than 20 microns is within 10 per cent of the estimated amount of clay mineral material in nine of the 13 samples and within five per cent in seven of the 13 samples.

The material in the samples which is coarser than 270-mesh would ordinarily be called sand. It probably adds no plasticizing value to the samples as mortar mix and should be considered as additive to the sand used in making mortar.

The significance of the particle-size data in relation to the results of other tests of the physical properties of the samples such as strength, plasticity, etc., is presented with the discussion of the results of these other tests.

MINERALOGICAL CHARACTER OF SAMPLES

By R. E. Grim

Clays and shales are primarily aggregates of very small crystalline particles of one or more members of a small number of minerals known as the clay minerals.[15] Analyses of a large number of clays and shales have shown that there are three important groups of clay minerals which are listed in table 5. In addition to the clay minerals, many clays and shales also contain variable quantities of quartz, pyrite, organic material, limonite, etc. Of these nonclay mineral constituents, quartz is usually the most abundant, so that many clays and shales are composed of clay mineral flakes of the order of size of 0.001 mm. or 1/25000 inch, together with variable quantities of grains of quartz.

Clays and shales frequently contain a considerable amount of material belonging to silt and sand size grades. This material is usually composed of nonclay minerals although individuual particles and aggregates of clay minerals of this size are not infrequent.

Composition of Clay Materials

Most of the shales that have been studied[16] are composed essentially of flakes of illite ranging in size from about 0.001 mm. to 0.020 mm. Some shales contain almost no quartz whereas others contain 50 per cent or more in grains from about 0.002 mm. to 0.2 mm. China clays are composed largely of flakes of kaolinite, ball clays of kaolinite with some illite. Like the shales the fireclays also contain quartz in amounts varying up to more than 50 per cent. Also in the fireclays the relative amounts of illite and kaolinite vary, so that some fireclays are known that are composed almost entirely of kaolinite whereas others contain about equal amounts of kaolinite and illite. The clay mineral in most fuller's earth and bentonites is montmorillonite. Surface clays in Illinois frequently contain illite as the essential clay mineral constituent; grains of quartz and also of calcite, if the clay is calcareous, are usually abundant. Gumbotil, the clayey material produced by the ancient weathering of glacial till, contains illite and montmorillonite, and occasionally small amounts of kaolinite.

Properties of the Clay Minerals

The clay minerals have different physical properties, and the physical properties of any clay or shale depend largely on the character of the clay minerals that compose it. The amount and kind of nonclay minerals are also important; for example, a clay containing 50 per cent quartz will not have the same properties as one containing only 10 per cent quartz.

Montmorillonite is found in extremely small particles (frequently less than 0.0001 mm.) or in larger flakes that are easily broken down in pugging to this extremely small size. Clays composed of montmorillonite have high plastic properties, high bonding strength, high shrinkage, and are not refractory.

Kaolinite occurs in particles larger than those of montmorillonite (usually larger than 0.001 mm.) and the particles are not

[15] Grim, R. E., Modern concepts of clay materials: Jour. Geology, vol. 50, pp. 225-275, 1942; Illinois Geol. Surv. Rept. Inv. 80, 1942.

[16] Grim, R. E., The relation of the composition to the properties of clays: Jour. Am. Ceramic Soc., vol. 22, No. 5, pp. 141-151, 1939; Illinois Geol. Surv. Cir. 45, 1939.

Table 5.—Important Clay Minerals

Name	Ideal Composition	Occurrence
Kaolinite	$(OH)_8Al_4Si_4O_{10}$	China clay, underclays, etc.
Illite	$(OH)_4K_y(Al_4 \cdot Fe_4 \cdot Mg_4 \cdot Mg_6)(Si_{8-y} \cdot Al_y)O_{20}$	Shales, underclays, surface clays
Montmorillonite	$(OH)_4Al_4Si_8O_{20} \cdot xH_2O$[a]	Bentonite, fuller's earth, surface clays

[a] In montmorillonite some Al may be replaced by Fe^{III} and Mg.

Table 6.—Mineral Composition of Samples Investigated

Sample No.	Clay minerals	Clay minerals per cent	Size of clay minerals[a]	Chief non-clay minerals	Maximum size of non-clay mineral	Comments
0	Illite	60	medium	quartz	0.05 mm	Contains grog and limonite.
1	Illite (10) Kaolinite (90)	70	fine	quartz	0.2 mm	Contains grog.
2	Illite	45	fine	quartz 70 calcite 30	2 mm	
3	Illite	60	fine	quartz 60 calcite 40	0.5 mm	Contains limonite.
4	Illite	45	coarse	quartz	0.2 mm	Contains limonite.
5	Illite	85	fine	quartz	1 mm	Contains limonite.
6	Illite	85	medium	quartz	0.15 mm	Contains abundant limonite. (5±%)
7	Illite	60	coarse	quartz	0.15 mm	Contains limonite.
8	Illite	70	coarse	quartz	0.5 mm	
9	Montmormillonite	75	fine	quartz	0.2 mm	Contains glauconite, feldspar and coarse mica.
10	Kaolinite	95	fine	quartz	0.06 mm	
11	Kaolinite (50) Illite (50)	60	medium	quartz	0.3 mm	
12	Illite	40	fine	quartz 65 calcite 35	0.2 mm	Contains limonite.
13	Illite (80) Kaolinite (20)	90	medium	quartz	0.06 mm	Contains appreciable pyrite.
14	Illite (35) Kaolinite (65)	60	medium	quartz	0.15 mm	Contains appreciable pyrite.
15	Kaolinite	5	fine	....	....	Non-clay material is cryptocrystalline silica in aggregate form.
16	Illite Montmorillonite	40	fine	quartz	1 mm	
17	Illite	50	coarse	quartz	0.25 mm	

[a] Coarse +0.02 mm; medium 0.02 mm-0.005 mm; fine —0.005 mm.

Table 6.—Mineral Composition of Samples Investigated—Concluded

Sample No.	Clay minerals	Clay minerals per cent	Size of clay minerals[a]	Chief non-clay minerals	Maximum size of non-clay mineral	Comments
18	Illite	60	medium	quartz	0.2 mm	Contains trace of calcite and few larger pebbles.
19	Illite	20	fine	quartz	0.15 mm	
20	Illite	75	medium	quartz	0.3 mm	Contains limonite.
21	Illite	75	coarse	quartz	0.3 mm	Contains limonite.

[a] Coarse +0.02 mm; medium 0.02 mm-0.005 mm; fine −0.005 mm.

easily reduced in size. Kaolinite clays tend to have lower shrinkage, bonding strength, and plastic properties than montmorillonite clays. They are also more refractory.

Illite may occur (1) in particles of very small size or in particles that are easily broken down to an extremely fine particle size, or (2) in larger flakes that resist reduction in size. Clays composed of the former variety are plastic and have high shrinkage and high bonding strength. Materials composed of the latter variety have low shrinkage, low bonding strength, and low plastic properties. In general, illite clays or shales are not refractory.

Analytical Results

Table 6 presents data on the character and abundance of the dominant clay minerals and the amount of quartz in the samples investigated. The shales range in composition from 85 to 45 per cent illite, the remainder being chiefly quartz. The illite in the shales is the variety that occurs in relatively large particles which are not easily reduced in size on working. The underclays show a range in clay mineral content of from 60 to 70 per cent and a variation in the relative abundance of illite from 10 per cent to 30 per cent of the total clay. The dominant clay mineral in the glacial till is illite, probably of the variety occurring in large flakes which are resistant to break-down. The nonclay portion of the glacial tills contains in addition to quartz, grains of calcite making up about 15 per cent of the total sample.

The kaolin sample is almost pure kaolinite and is distinctive because the kaolinite occurs in flakes smaller than those frequently characteristic of this mineral. Sample 13 contains only about 10 per cent nonclay mineral and the illite is of the variety that breaks down easily into extremely small particles when worked with water. The fuller's earth is illustrative of clays composed chiefly of montmorillonite. Samples 16, 19, and 15 are examples of fine-grained materials with large amounts of non-clay minerals. Gumbotil (sample 16) is interesting because of the presence of a small amount of montmorillonite. It is known that this clay mineral, even though present in only small amounts, has a very great effect on the physical properties of a clay.

PROPERTIES OF MORTARS CONTAINING ILLINOIS CLAYS AND SHALES

By R. K. Hursh

OBJECTIVES OF STUDY

The studies of mortars containing Illinois clays and shales as plasticizers had four major objectives, (1) to determine the effects of various amounts of these clays and shales on the properties of mortars and from these data to ascertain the optimum additions as plasticizers in mortars of suitable structural and working characteristics, (2) to find out whether certain varieties of these clays and shales possess superior properties as plasticizers, (3) to discover the effects of fineness of grinding of clays and shales on the properties of mortars, and (4) to evaluate the significance of ultimate particle size, mineral composition, and slaking characteristics of clays and shales on the properties of mortars.

The importance of objectives 1 and 2 is self evident. Objective 3 is significant in the fact that an important cost item in the commercial production of a clay or shale mortar mix is the fineness to which it must be ground to give satisfactory results. In previous investigations and in commercial mortar mix it has been the practice to use very finely ground or air-floated clay or shale. However, instances are on record of the use of comparatively coarsely ground clay materials in mortars which have maintained adequate strength and have withstood weathering over a considerable period of years. Tests were therefore made on mortars containing clay or shale ground to pass 80-mesh, 100-mesh, and 8-mesh sieves. The last material was ground only in a dry pan and if satisfactory could obviously be

Table 7.—Dry Screen Analyses of Clay Materials of 8-mesh Grind

Sample No.	Per cent retained on sieve of given mesh					
	16	30	50	100	200	-200
Shales						
0	18.0	15.5	12.3	8.5	6.4	39.3
4	15.4	15.4	12.1	7.2	5.5	44.4
5	16.4	18.2	13.0	15.0	9.3	28.1
6	15.8	16.9	15.5	12.6	14.8	24.4
7	11.5	13.7	8.9	18.4	0	47.5
8	11.8	14.0	11.6	8.6	9.8	44.2
17	7.4	9.8	6.6	8.2	9.1	58.9
18	5.2	30.2	17.9	12.8	6.8	27.1
20	12.7	15.6	11.4	27.4	0	32.9
Underclays						
1	7.0	15.1	23.9	15.0	13.0	26.0
11	22.5	17.4	10.5	21.2	0	28.4
14	10.9	21.1	12.8	22.0	0	33.2
Glacial till						
2	0.5	4.8	11.8	32.8	0	50.1
3	17.6	18.9	18.1	14.2	10.2	21.0
12	12.7	17.5	14.3	14.4	9.1	32.0
16	8.6	16.1	19.3	22.5	11.1	22.4
Miscellaneous						
9	25.0	21.4	14.5	13.5	8.4	17.2
10	5.8	15.3	19.7	19.9	22.3	17.0
13	12.7	19.5	21.1	18.5	13.5	14.7
19	3.3	6.6	7.8	18.0	0	64.3
15	18.8	12.0	7.5	8.9	8.1	44.7

Table 8.—Results of Slaking Tests

Sample No.	Per cent retained on 20-mesh sieve	Per cent retained on 200-mesh sieve	Per cent passing 200-mesh sieve
Shales			
0	5	8	87
4	1	10	89
5	14	19	67
6	5	12	83
7	5	11	84
8	1	53	46
17	3	10	87
18	14	33	53
20	5	22	73
Average	6	20	74
Underclays			
1	3	18	79
11	4	14	82
14	8	17	75
Average	5	16	79
Glacial till			
2	1	10	89
3	2	8	90
12	2	10	88
16	1	15	84
Average	2	11	87
Miscellaneous			
9	11	17	72
10	0	2	98
13	0	14	86
19	0	4	96

produced more cheaply than the finer sized materials.

The purpose in objective 4 was to ascertain whether such properties as ultimate particle size, mineral composition, or slaking characteristics might provide a basis for predicting the behavior of a clay or shale as a plasticizer in mortar, thereby making it possible to eliminate unsuitable materials without experimental preparation of mortars and tests of their strength, water retention, aging, and other properties.

CHARACTER OF MATERIALS USED IN TESTS

PARTICLE SIZE OF GROUND CLAYS AND SHALES

No tests were made to determine in detail the particle-size distribution of the clays and shales that were ground to pass 80-mesh or 100-mesh sieves. Sieve tests were made, however, on the 8-mesh pan-ground material because its coarser top size offered a much greater opportunity for variation than was possible in more finely ground materials. Table 7 gives results of dry sieve test on 8-mesh clays and shales made with a Rotap and standard sieves in accordance with A.S.T.M. specification C 136-39.

SLAKING CHARACTER OF CLAYS AND SHALES

It was recognized that there would be considerable slaking of the clay materials in the process of mixing the mortar and that this would result in a much larger proportion of fine particles than was indicated by the dry screen tests. Therefore, the 8-mesh samples were subjected to a slaking test which was designed to simulate the effect of the wetting and mixing operation in preparing mortar.

A 50-gram sample of the clay, previously dried at 110°C., was poured into 75 cc. of water and blunged for 1 minute in an electric drink mixer. The slip was then sieved on 20- and 200-mesh sieves. The oversize material was dried and weighed. Results of the test are given in table 8 which shows, in general, that the slaked material is finest among the glacial tills, coarsest for the shales, and intermediate for underclays, although some samples gave results which are exceptions.

PORTLAND CEMENT

A Portland cement of a standard brand was used, and enough for the entire investigation was obtained at the start and stored under suitable conditions to prevent deterioration during the period of preparation of the mortars.

MORTAR SAND

A sand from Ottawa which corresponded to the specifications for a mortar sand (A.S.T.M. C 109-37T) was used. The screen analyses of the two lots of this material are shown and compared with the specification limits in table 9.

Table 9.—Screen Analysis of Mortar Sand

Per cent retained on mesh	Specification requirement	First lot	Second lot
100	98±2	97.0	97.0
50	72±5	76.0	67.0
30	2±2	0.7	0.5
16	0	0	0

The dry screen tests of the mortar sand were made with a Rotap and standard sieves in accordance with the A.S.T.M. specification C 136-39.

BULK DENSITY OF THE RAW MATERIALS

Measurements of the bulk density were made on each of the raw materials used. The weight of dry ground clay or shale required to fill a container of measured volume without packing or rodding was determined. This procedure was not in accord with the standard method for measurement of the unit weight of aggregate, A.S.T.M. C 29-39, but it gave more consistent results for the clay materials than several other methods that were tried. It also corresponds more closely with the volume-weight relationships of the materials as they might be used in the volume proportioning of mortar batches.

The values for the bulk density in pounds per cubic foot of the loose dry materials, each figure representing the average of several determinations, are included in table 10. Also shown are the approximate proportions by volume of the loose dry materials in each mortar batch. These were calculated by use of the bulk densities from the weight ratios used in making up the mortars.

PREPARATION OF MORTARS

MORTAR MIXTURES

All of the mortars were prepared in the proportion by weight of one part of a mixture of cement and clay or shale to three parts of sand. Variations in the amount of clay used were made by substitution of clay for a portion of the cement that would be used in a 1:3 cement-sand mortar. A series of four mixtures was prepared with each of the clay materials with the ratios of clay and cement by weight of 20:80, 30:70, 40:60 and 50:50, respectively. The same proportions were used in the mortars containing lime hydrate instead of clay.

The designation of the mixtures indicates the sample number, the percentage of clay material in the clay-cement portion, and the screen mesh through which the clay was passed. For example, 4-30-8 designates the mortar mixture with sample 4, a 30 per cent replacement of cement in the cement-clay portion, and the 8-mesh grind. The mortars containing lime hydrate are designated by L-20, L-30, etc., to indicate the material and the percentage replacement of cement in the 1:3 mortar. The masonry cement mortar is designated by M and the cement-sand mortar by 1C-3S.

MIXING OF MORTARS

Mortars were prepared by the method specified for masonry cement, A.S.T.M. C 91-38T, described as follows:

"The mortars shall be mixed in a nonabsorbent bowl of about one-gallon capacity. A measured quantity of water shall be poured into the bowl which has previously been wiped with a damp cloth. A 500-g.

Table 10.—Proportions of Mortar Ingredients

Sample No.	Weight of loose materials lb. per cu. ft.	Mortar No.	Parts by weight			Approximate per cent by volume of loose dry materials			Approximate ratio by volume of loose dry materials		
			Clay	Cement	Sand	Clay	Cement	Sand	Clay	Cement	Sand
0	71.4	0-20-8	20	80	300	6.2	24.4	69.4	.25	1	2.84
		0-30-8	30	70	300	9.4	21.4	69.2	.44	1	3.24
		0-40-8	40	60	300	12.5	18.3	69.2	.68	1	3.78
		0-50-8	50	50	300	15.6	15.3	69.2	1.02	1	4.53
4	68.4	4-20-8	20	80	300	6.5	24.4	69.2	.27	1	2.84
		4-30-8	30	70	300	9.7	21.3	69.0	.46	1	3.24
		4-40-8	40	60	300	12.9	18.2	68.8	.71	1	3.78
		4-50-8	50	50	300	16.1	15.2	68.7	1.06	1	4.53
5	72.9	5-20-8	20	80	300	6.1	24.5	69.5	.25	1	2.84
		5-30-8	30	70	300	9.2	21.4	69.3	.43	1	3.24
		5-40-8	40	60	300	12.2	18.4	69.3	.67	1	3.78
		5-50-8	50	50	300	15.3	15.3	69.3	1.00	1	4.53
6	67.7	6-20-8	20	80	300	5.9	24.4	69.2	.27	1	2.84
		6-30-8	30	70	300	8.8	21.3	68.9	.46	1	3.24
		6-40-8	40	60	300	13.1	18.2	68.7	.72	1	3.78
		6-50-8	50	50	300	16.3	15.1	68.6	1.08	1	4.53
7	65.0	7-20-8	20	80	300	6.8	24.3	69.0	.28	1	2.84
		7-30-8	30	70	300	9.2	21.2	68.6	.48	1	3.24
		7-40-8	40	60	300	13.5	18.1	68.4	.75	1	3.78
		7-50-8	50	50	300	16.8	15.0	68.1	1.12	1	4.53
8	80.5	8-20-8	20	80	300	5.5	24.7	69.9	.23	1	2.84
		8-30-8	30	70	300	8.4	21.6	70.0	.39	1	3.24
		8-40-8	40	60	300	11.2	18.6	70.2	.60	1	3.78
		8-50-8	50	50	300	15.1	15.5	70.4	.91	1	4.53
17	65.2	17-20-8	20	80	300	6.8	24.3	69.0	.28	1	2.84
		17-30-8	30	70	300	9.1	21.2	68.6	.48	1	3.24
		17-40-8	40	60	300	13.5	18.1	68.4	.75	1	3.78
		17-50-8	50	50	300	16.8	15.0	68.1	1.12	1	4.53
18	85.7	18-20-8	20	80	300	4.8	24.8	70.2	.21	1	2.84
		18-30-8	30	70	300	7.9	21.7	70.4	.37	1	3.24
		18-40-8	40	60	300	11.6	18.7	70.7	.57	1	3.78
		18-50-8	50	50	300	13.3	15.7	71.0	.85	1	4.53
20	76.3	20-20-8	20	80	300	5.9	24.6	69.7	.24	1	2.84
		20-30-8	30	70	300	8.8	21.5	69.7	.41	1	3.24
		20-40-8	40	60	300	11.8	18.5	69.8	.64	1	3.78
		20-50-8	50	50	300	14.7	15.4	69.9	.94	1	4.53
1	83.5	1-20-8	20	80	300	5.4	24.6	70.0	.22	1	2.84
		1-30-8	30	70	300	8.1	21.7	70.2	.37	1	3.24
		1-40-8	40	60	300	10.9	18.7	70.4	.58	1	3.78
		1-50-8	50	50	300	13.6	15.6	70.8	.88	1	4.53
11	89.1	11-20-8	20	80	300	5.1	24.7	70.2	.21	1	2.84
		11-30-8	30	70	300	7.7	21.8	71.5	.35	1	3.24
		11-40-8	40	60	300	10.2	18.8	71.0	.55	1	3.78
		11-50-8	50	50	300	12.9	15.8	71.3	.82	1	4.53
14	88.4	14-20-8	20	80	300	4.6	24.8	70.6	.21	1	2.84
		14-30-8	30	70	300	7.7	21.8	70.5	.35	1	3.24
		14-40-8	40	60	300	10.3	18.7	71.0	.55	1	3.78
		14-50-8	50	50	300	13.0	15.7	71.3	.83	1	4.53

Table 10.—(Concluded)

Sample No.	Weight of loose materials lb. per cu. ft.	Mortar No.	Parts by weight			Approximate per cent by volume of loose dry materials			Approximate ratio by volume of loose dry materials		
			Clay	Cement	Sand	Clay	Cement	Sand	Clay	Cement	Sand
2	65.9	2–20–8	20	80	300	6.1	24.3	69.6	.28	1	2.84
		2–30–8	30	70	300	10.0	21.2	68.8	.47	1	3.24
		2–40–8	40	60	300	13.4	18.1	68.5	.74	1	3.78
		2–50–8	50	50	300	16.7	15.1	68.2	1.11	1	4.53
3	70.3	3–20–8	20	80	300	6.3	24.4	69.3	.26	1	2.84
		3–30–8	30	70	300	9.5	21.3	69.2	.45	1	3.24
		3–40–8	40	60	300	12.7	18.3	69.0	.69	1	3.78
		3–50–8	50	50	300	15.8	15.2	69.0	1.04	1	4.53
12	76.8	12–20–8	20	80	300	5.8	24.6	69.6	.24	1	2.84
		12–30–8	30	70	300	8.8	21.5	69.7	.41	1	3.24
		12–40–8	40	60	300	11.7	18.5	69.8	.63	1	3.78
		12–50–8	50	50	300	14.6	15.4	70.0	.95	1	4.53
16	80.4	16–20–8	20	80	300	5.6	24.6	70.8	.23	1	2.84
		16–30–8	30	70	300	8.4	21.6	70.0	.39	1	3.24
		16–40–8	40	60	300	11.2	18.6	70.2	.61	1	3.78
		16–50–8	50	50	300	14.1	15.5	70.4	.91	1	4.53
9	45.9	9–20–8	20	80	300	9.4	23.6	67.0	.40	1	2.84
		9.30–8	30	70	300	13.8	20.3	65.9	.68	1	3.24
		9–40–8	40	60	300	18.2	17.1	64.7	1.19	1	3.78
		9–50–8	50	50	300	22.3	14.0	63.7	1.58	1	4.53
10	54.6	10–20–8	20	80	300	7.8	23.5	68.7	.33	1	2.84
		10–30–8	30	70	300	11.9	20.8	67.3	.57	1	3.24
		10–40–8	40	60	300	15.7	17.6	66.7	.89	1	3.78
		10–50–8	50	50	300	19.5	14.6	65.9	1.34	1	4.53
13	81.1	13–20–8	20	80	300	5.4	24.1	70.5	.23	1	2.84
		13–30–8	30	70	300	8.3	21.6	70.1	.38	1	3.24
		13–40–8	40	60	300	11.2	18.6	70.2	.60	1	3.78
		13–50–8	50	50	300	14.0	15.6	70.4	.90	1	4.53
19	76.6	19–20–8	20	80	300	5.8	24.5	69.7	.24	1	2.84
		19–30–8	30	70	300	8.8	21.5	69.7	.41	1	3.24
		19–40–8	40	60	300	11.7	18.5	69.8	.64	1	3.78
		19–50–8	50	50	300	14.7	15.4	69.9	.96	1	4.53
15	68.8	15–20–8	20	80	300	6.5	24.4	69.1	.27	1	2.84
		15–30–8	30	70	300	9.7	21.3	69.0	.45	1	3.24
		15–40–8	40	60	300	12.9	18.3	68.8	.71	1	3.78
		15–50–8	50	50	300	16.1	15.2	68.7	1.27	1	4.53

Wt. per cu. ft.
Cement 72.9
Sand 96.5

portion of the cement shall then be added and stirred into the water with the fingers of one hand until all the cement is wetted. Approximately 800 g. of sand shall then be added and the stirring continued for 30 seconds. The remainder of 1500 g. of sand shall then be added and the mortar mixed for 75 seconds by vigorous and continued stirring, squeezing and kneading with one hand. The mortar shall then be allowed to stand for 60 seconds and then mixed for another 60 seconds. During the operation of mixing the hands shall be protected by rubber gloves."

In these tests the cement and clay were thoroughly dry-mixed in the required proportions for each batch and then introduced as the cement portion in the above procedure.

STANDARD CONSISTENCY OF MORTARS

In order to obtain comparative results in tests of different mortars, a standard consistency is specified which fixes the water content of each mixture and for each type of test. A lower water content and a less fluid mixture is used for forming cubes for compression tests than in preparing mortars for the water retention test or as normally used in masonry construction. The consistency of the mortars was determined by means of the flow table and in accordance with A.S.T.M. specification C 91-38T for masonry cement.

"The flow table consists of a rigid frame with a flat circular top, so mounted on a vertical shaft that it can be raised and dropped through a fixed height of ½ in. ± 1/32 in. by means of a rotated cam. The top shall be of noncorrodible metal 10 in. in diameter and with the attached shaft shall weight 9 lbs. ± 1 oz. The frame shall be attached rigidly to a concrete pedestal, which in turn shall be attached rigidly to the floor. The concrete pedestal shall be at least 8 in. in diameter and 25 in. high and shall weigh at least 100 lbs. The mold shall be of noncorrodible material, 4 in. in inside diameter at the base, 2¾ in. at the top and 2 in. high."

"The mortar shall be mixed with a measured quantity of water in accordance with the procedure described. The top of the flow table shall be carefully wiped dry and the flow mold placed at the center and filled with mortar. In filling the mold the mortar shall not be rammed, but gently smoothed off level with the top of the mold by aid of a trowel and the mold then removed. Immediately the table shall be dropped through a height of ½ in., 25 times in 15 seconds. The flow is the resulting increase in diameter of the mortar mass, expressed as a percentage of the original diameter. Trial mortars shall be made with varying percentages of water until the standard consistency is obtained. . . . Each trial shall be made with fresh mortar. The quantity of water shall be expressed as a percentage of the weight of the combined dry materials."

"The mortar shall be of standard consistency for the molding of compression test cubes when the flow is 65 to 80 per cent. Mortars for the water retention test shall have a flow of 100 to 115 per cent."

RESULTS OF TESTS ON MORTARS

Water Requirements for Standard Consistency

The amount of water required for standard consistency is shown in relation to the clay addition in the mortar in table 11 and curves of figure 3. The water content of the mortar is expressed in percentage of the weight of the dry materials (cement + clay + sand) in the mixture. The upper lines, marked R, represent the values for standard flow of 100 to 115 per cent for water retention tests. The lower curves, marked C, are for the 65 to 80 per cent flow required for making cubes for compression tests.

The water requirement is shown for tests with the 8-mesh, 80-mesh, and 100-mesh clay for comparison. For most samples there was little difference in the amount of water used for coarse and finely ground clays, indicating that most of the coarse clay particles slake sufficiently in the period of mixing the mortar to give a degree of fineness about the same as that of the more finely ground materials.

Considering the samples as groups, the data in figure 3 show little difference between the shales, underclays, and glacial tills. In each group all of the samples in mortars containing 40 per cent of clay in the clay-cement portion required a water content between 17 and 19 per cent for the standard flow of 100 to 115 per cent. For the stiffer consistency, 65 to 80 per cent flow, the mortars contained between 15 and 16 per cent of water. Over the range of mixtures examined, an addition of 0.5 to 0.6 per cent of water was necessary with each increase of 10 per cent of clay substituted for cement in the mortar.

Water Retention of Mortars

The water retentivity of the mortar is considered to be, in some measure, an index of its workability. It also indicates the comparative resistance of the mortar to drying out when in contact with absorbent masonry units, with consequent weakening of the bond between the mortar and the structural unit.

DESCRIPTION OF TESTS

The method and the apparatus for making the water retention test are described in

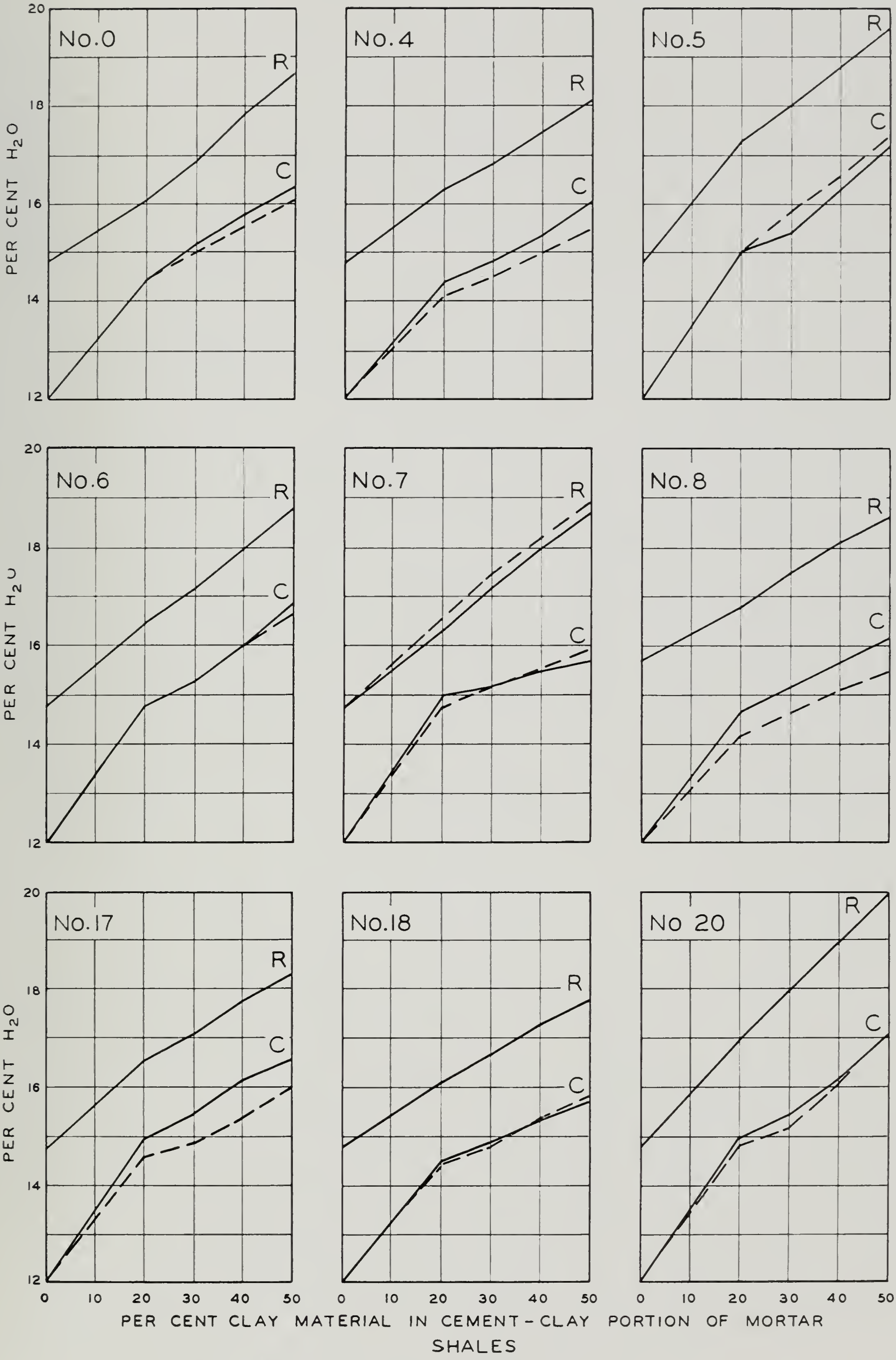

FIG. 3a.—Water requirement for standard consistency of mortars.

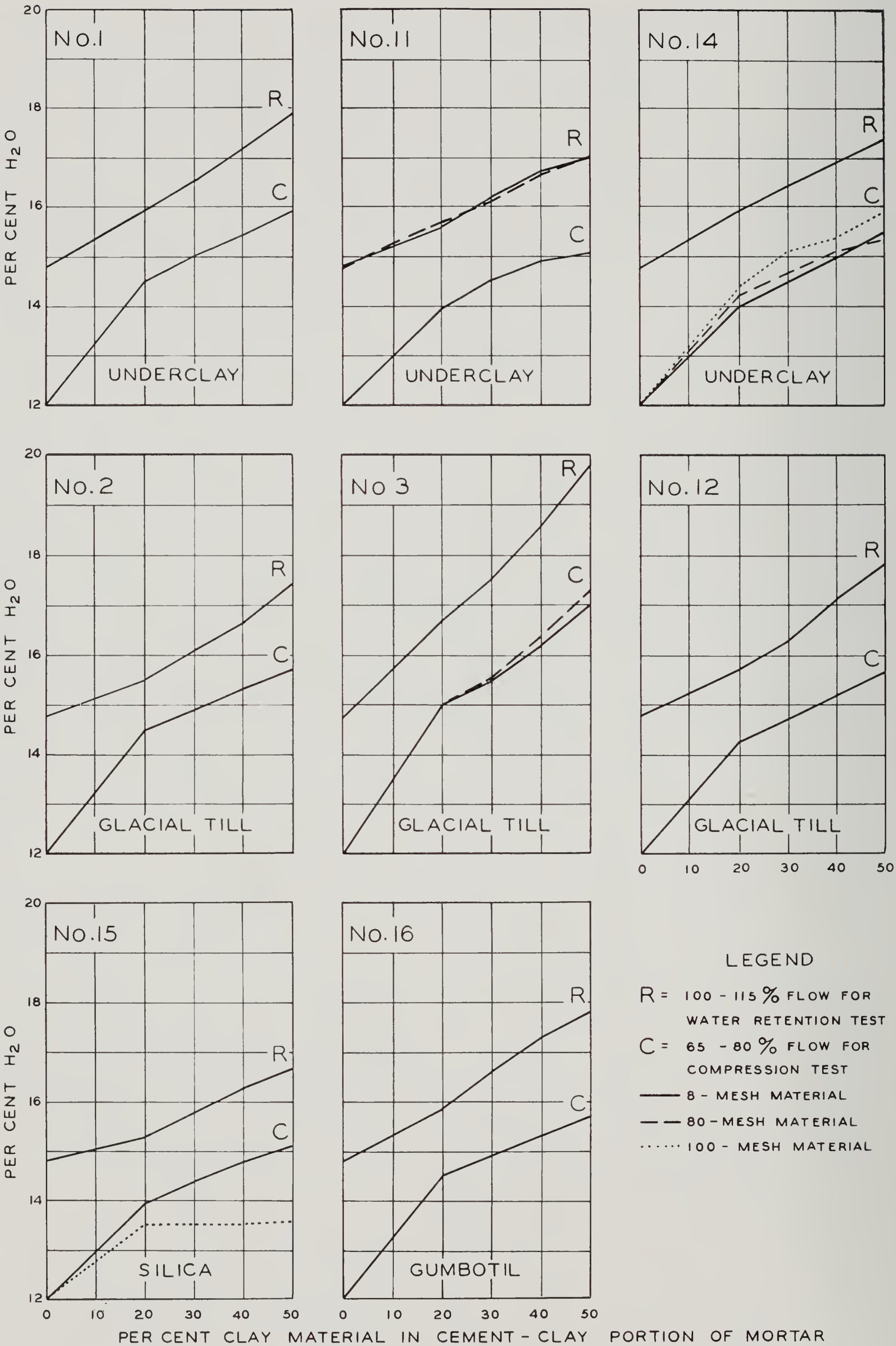

Fig. 3b.—Water requirement for standard consistency of mortars.

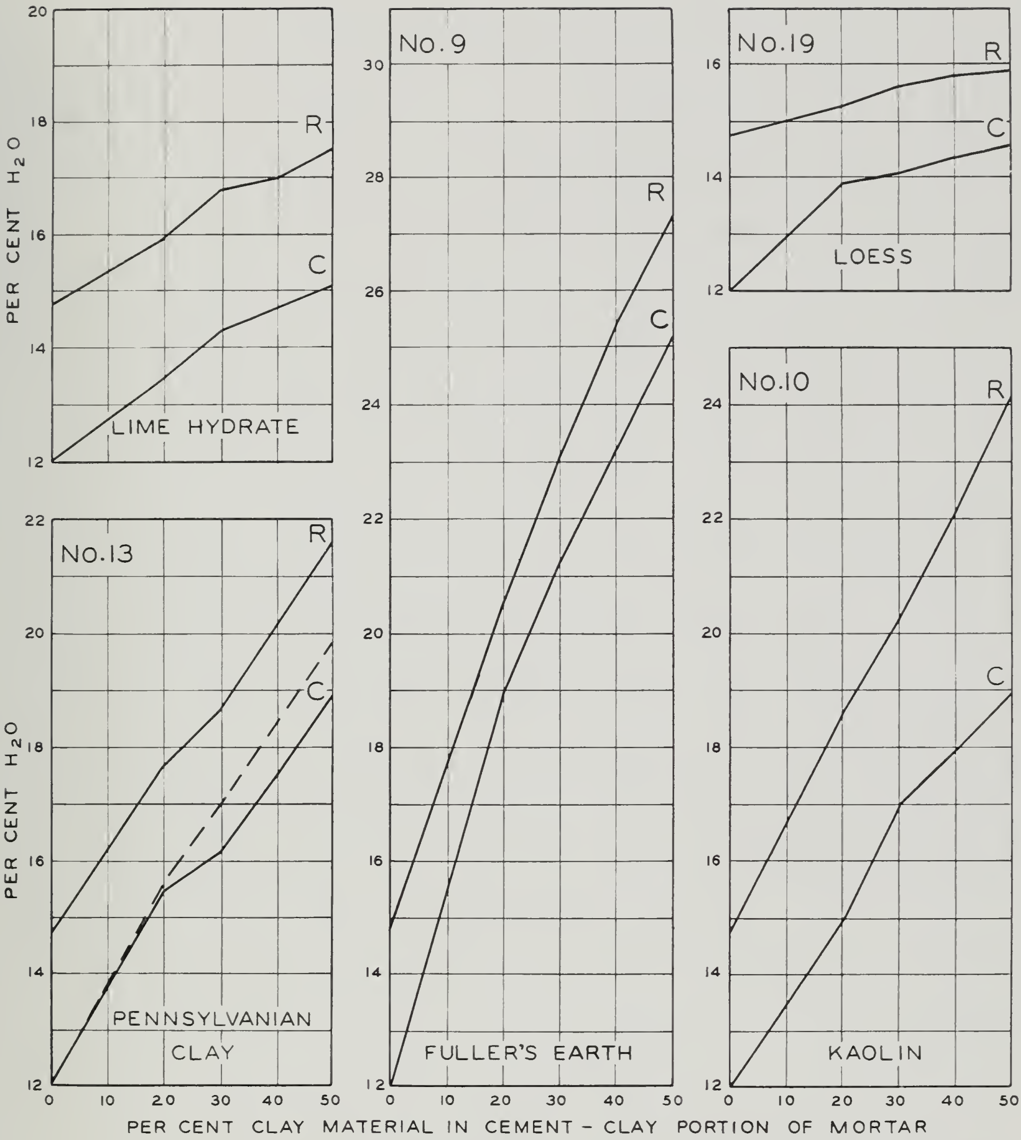

FIG. 3c.—Water requirement for standard consistency of mortars.

the A.S.T.M. specification C 91-38T for masonry cement. The test procedure is briefly described as follows:

The mortar is mixed by the standard method with a sufficient water content to give 100 to 115 per cent flow. Immediately after the flow-table test, the mortar used is remixed for 30 seconds with that remaining in the bowl, then evenly distributed on a dampened filter paper in the perforated dish of the water retention test apparatus and struck off flush with the top edge of the dish by means of a straight edge. The dish is then seated on a wetted gasket in the suction apparatus and subjected to a 2-in. vacuum for 60 seconds. The mortar is then removed with a spatula and placed in the flow mold, each portion being puddled. The flow is again determined and expressed as a percentage of the original flow for the water retention value of the mortar. The time from the mixing for the first flow test to the completion of the operation shall not exceed seven minutes.

Table 11.—Water Retention of Mortars

Sample No.	Water required for 100–115% flow				Water retention % of original flow				Approx. % clay[a] required to give water retention of 65%
	Per cent clay				Per cent clay				
	20	30	40	50	20	30	40	50	8-mesh
8-mesh clay									
Shale									
0	16.1	16.9	17.9	18.7	55.7	61.6	67.5	69.6	35
4	16.3	16.8	17.5	18.1	54.7	64.7	66.5	70.2	30
5	17.3	18.0	18.8	19.6	55.5	66.6	69.4	72.9	28
6	16.5	17.2	18.0	18.8	61.0	67.5	73.6	74.9	26
7	16.3	17.2	18.0	18.7	51.8	59.7	63.9	69.8	42
8	15.9	16.5	17.1	17.7	47.7	50.7	54.2	59.4	—
17	16.6	17.1	17.8	18.4	52.2	63.7	65.4	67.2	36
18	16.1	16.7	17.3	17.8	46.2	53.8	60.7	62.9	—
20	17.0	17.9	19.0	20.0	58.0	64.0	65.1	69.8	40
Underclays									
1	15.9	16.5	17.2	17.9	53.1	57.6	66.9	72.9	38
11	15.6	16.2	16.7	17.2	32.0	34.9	40.9	45.1	—
14	15.9	16.4	16.9	17.4	48.0	53.0	59.0	62.0	—
Glacial till									
2	15.5	16.1	16.7	17.4	49.2	60.7	67.2	70.2	36
3	16.7	17.5	18.6	19.8	63.2	69.9	76.5	79.6	22
12	15.7	16.3	17.1	17.8	55.7	62.4	70.1	71.0	33
16	15.9	16.6	17.3	17.9	53.0	60.8	66.0	69.0	38
Miscellaneous									
9	20.6	23.2	25.5	27.5	51.5	57.7	61.7	62.0	—
10	18.7	20.3	22.2	24.1	75.3	79.0	81.3	82.5	16
13	17.7	18.7	20.2	21.6	66.9	70.5	73.1	72.6	19
19	15.3	15.7	15.9	16.0	40.7	47.8	53.8	58.7	—
15	15.3	15.8	16.3	16.7	20.4	22.0	19.9	20.0	—
Lime	16.0	16.8	17.0	17.5	45.7	55.5	58.0	64.0	52
80-mesh clay									
Shale									
7	16.6	17.5	18.2	18.9	54.0	62.8	65.5	72.7	38
Underclay									
14	16.2	16.7	17.2	17.7	54.6	61.2	66.8	69.3	37
Glacial till									
3	16.9	17.8	18.8	20.2	65.3	73.8	74.9	78.9	25

Cement Mortar 1C3S water required 14.8, water retention 27.2.
Masonry Mortar M water required 16.5, water retention 73.3.

[a] Per cent of clay in clay-cement portion of the mortar.

RESULTS

Data showing the amount of water required for standard consistency, 100 to 115 per cent flow, and the water retention values expressed as per cent of initial flow, are given in table 11 for all of the mortars in which the dry-pan ground clay passing 8-mesh was used. Each value represents the average of three or more individual tests. These separate tests were generally in close agreement. The relationship of the water retention values to the percentage of the various samples in the cement-clay portion of the batches is shown by curves in figure 4. The results for samples 7, 14, and 3 are also shown for mortar in which the material ground to pass 80-mesh was used.

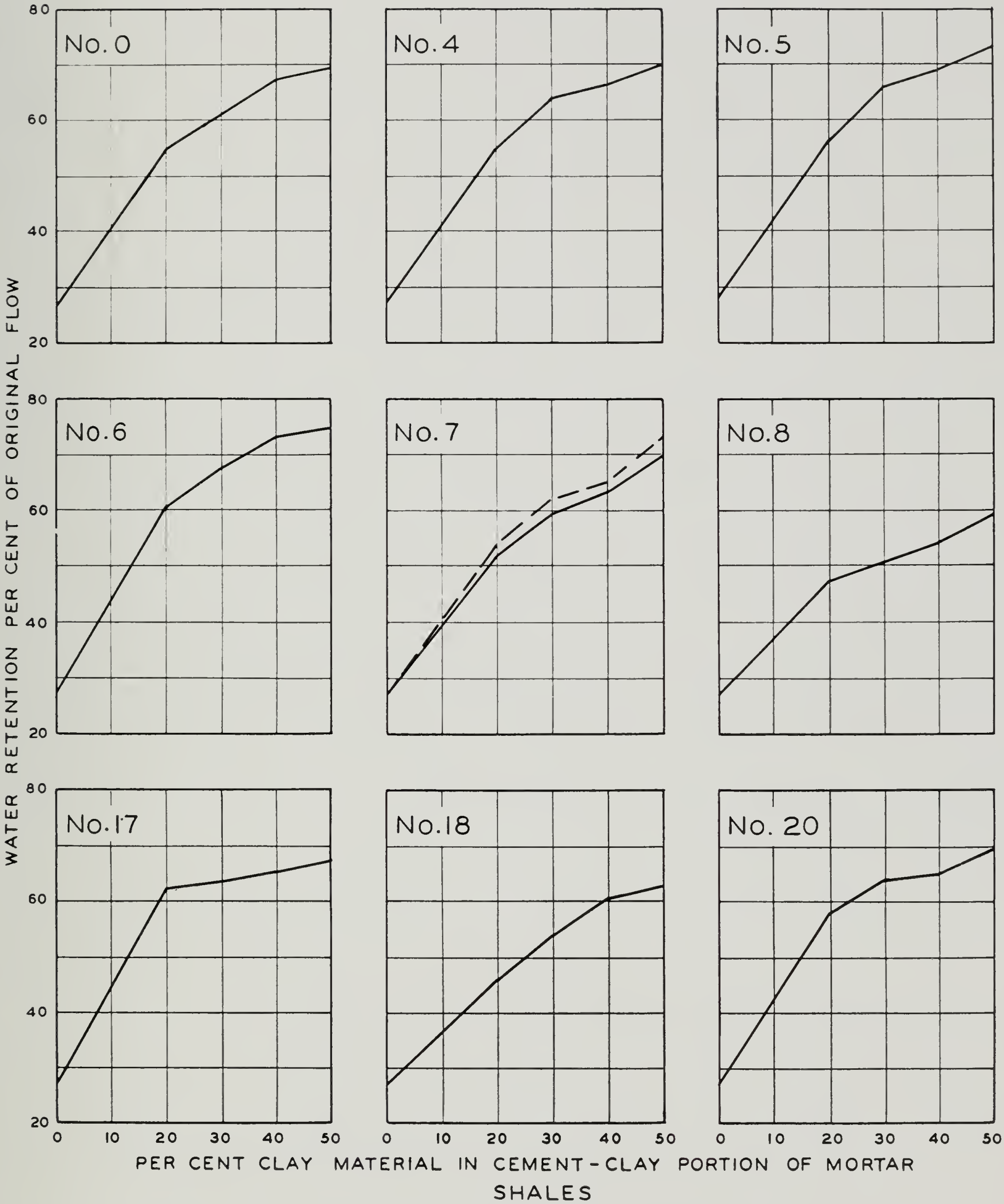

Fig. 4a.—Relation of water retention to per cent of clay material in the cement-clay portion of the mortar.

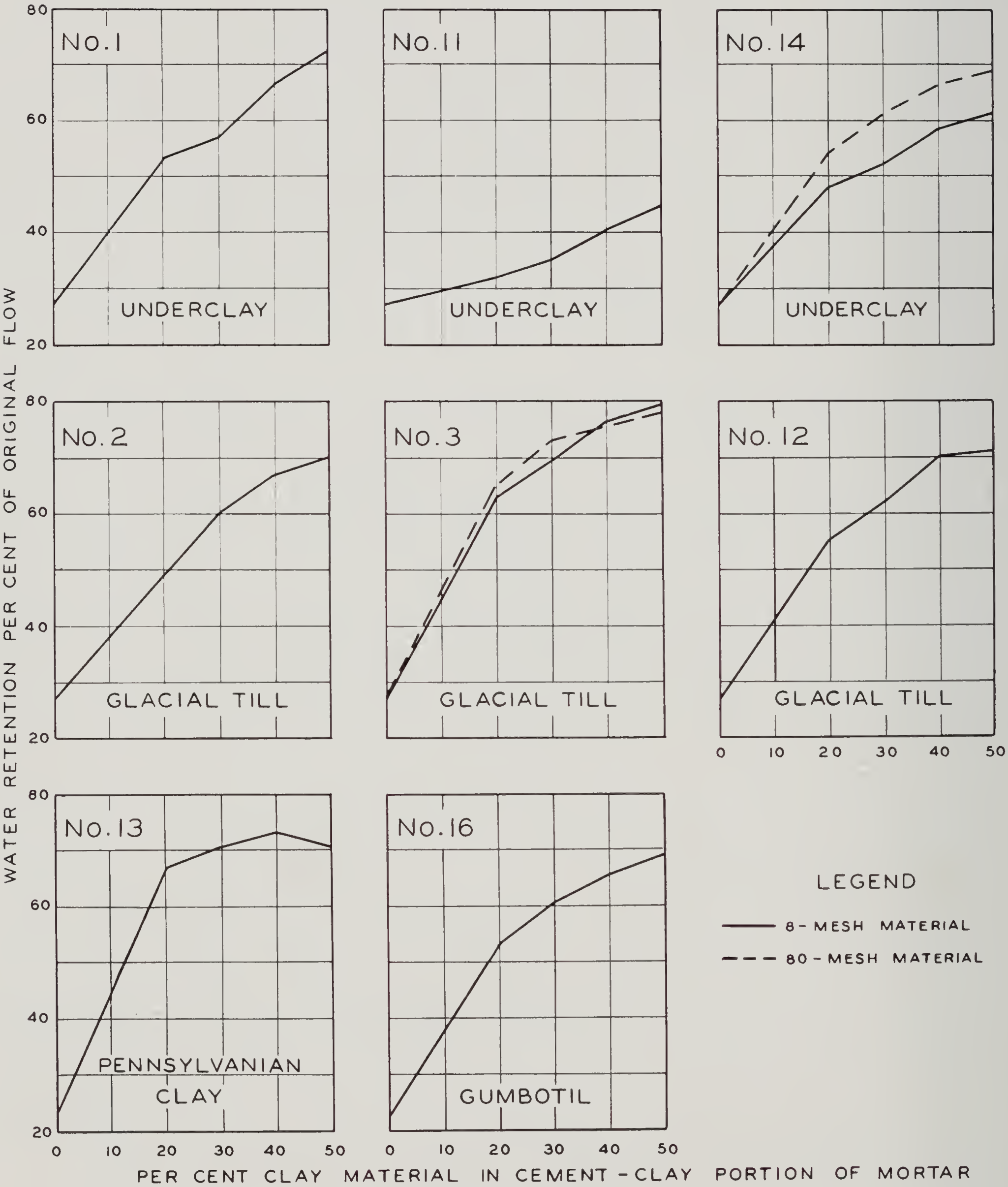

Fig. 4b.—Relation of water retention to per cent of clay material in the cement-clay portion of the mortar.

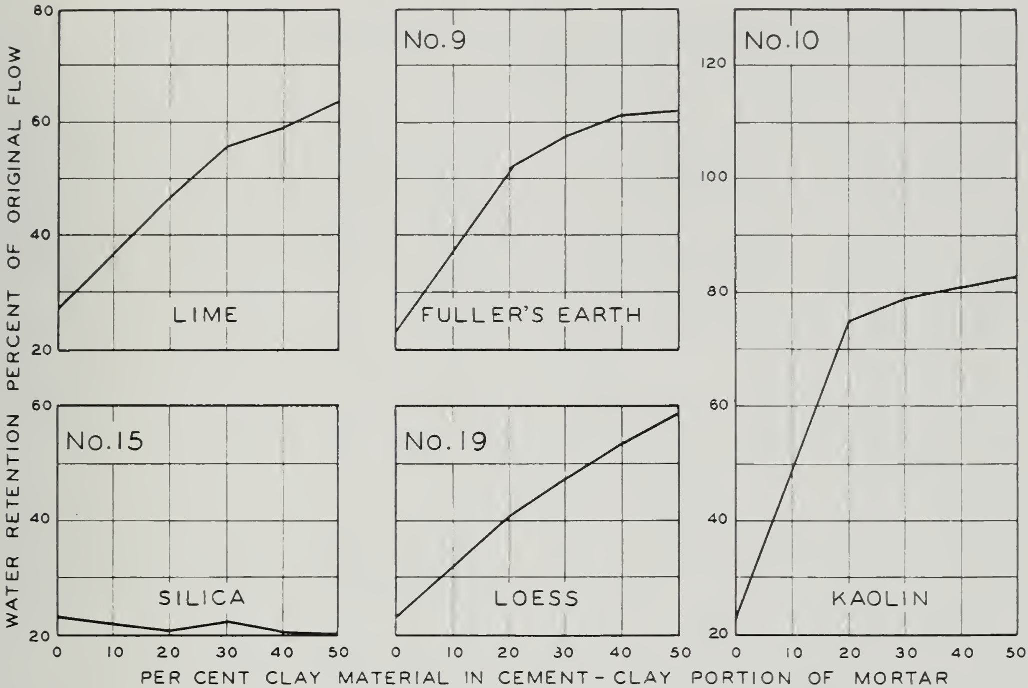

FIG. 4c.—Relation of water retention to per cent of clay material in the cement-clay portion of the mortar.

These indicate the comparative effects of coarse and fine grinding for samples which were selected as representative of the shales, underclays, and glacial tills respectively.

A water retention value of 65 per cent is required for mortar by Federal Specification SS-0-181b. From the curves, the approximate amount of each clay needed in the cement-clay portion of the mortar to meet this requirement has been determined and the values are included in table 11.

The information in table 11 in part may be summarized with reference to types of samples as shown in table 12.

These data and those in table 10 indicate that the glacial tills are the most effective plasticizing materials in the mortar. Of the three groups the underclays seem to have the lowest water retention although the range of values in the small number of samples indicates that the averages cannot be taken as representative of this type of material as a whole.

The average water retention of mortars containing shales and glacial tills is greater than the water retention of the lime mortar for both the 30 and 40 per cent mixtures. Seven of the nine shales in the 30 per cent mortar had higher water retention than the lime mortar, whereas eight of the nine exceeded the lime in the 40 per cent mixtures. All of the glacial tills gave higher water retention than the lime in both mixtures.

As compared to lime, seven of the nine shales and all of the glacial tills required less plasticizer to give a water retention value of 65 per cent, as required by the Federal Specification SS-0-181b.

However, the amount of underclay plasticizer required to meet these specifications exceeds the amount of lime in the case of two of the three underclays.

From these results it appears that mortars containing most of the samples substituted for 30 to 40 per cent of the cement would better resist being dried out due to absorption of water by porous materials than would similar mortars containing lime. Also smaller amounts of these clay materials would give the water retention values required by specification.

It is also to be noted that the finer grinding of the clays or shales used as admixture increases the plasticity and the water retention values for the mortar and therefore reduces the amount of clay required to meet the specification.

Table 12.—Summary of Water Retention Data

Type of material	Water retention in per cent of initial flow				Per cent clay material required in clay-cement portion of mortar for 65 per cent flow	
	30 per cent clay in cement-clay portion of mortar		40 per cent clay in cement-clay portion of mortar			
	Range	Average	Range	Average	Range	Average
Shales	51–68	61	54–74	65	26–60	40
Underclays	35–58	48	51–67	56	38–80	60
Glacial tills	61–70	63	67–77	70	22–38	32
Lime[a]		56		59		52

[a] One sample only.

Time of Set of Mortar

The time of initial set and of final set was determined by means of the Vicat needle (A.S.T.M. C 77-39) for mortars containing lime and shale admixtures and for the masonry mortar and the plain cement mortar. Although some of the shale-cement mortars required less time for setting than other mortars, there was no consistent relationship between this and any other observed properties of the materials. The data did not seem to be significant enough to warrant determinations for all of the mixtures. It may be stated that the hardening of mortars with clay admixtures is, in general, not greatly different than that of lime-cement or masonry mortars. Data for time of set of some of the mixtures are given in table 13.

Table 13.—Time of Set of Mortars, Vicat Needle

Mix No.	Time of initial set		Time of final set		Mix No.	Time of initial set		Time of final set	
	hrs.	min.	hrs.	min		hrs.	min.	hrs.	min.
IC–3S	4	51	6	3	6–20–8	3	43	6	4
					6–30–8	3	36	5	57
M	4	2	4	41	6–40–8	3	29	5	50
					6–50–8	3	39	5	9
L–20	4	35	7	58					
L–30	4	28	7	51	7–20–8	4	43	6	35
L–40	4	20	7	43	7–30–8	4	36	6	28
L-50	3	49	7	35	7–40–8	4	39	7	11
					7–50–8	4	21	7	24
4–20–8	5	33	7	15					
4–30–8	4	40	6	9	8–20–8	4	23	6	35
4–40–8	4	34	7	2	8–30–8	3	54	5	37
4–50–8	4	39	7	21	8–40–8	4	58	6	49
					8–50–8	4	51	7	47
5–20–8	4	30	6	—					
5–30–8	4	51	5	44	17–20–8	3	46	6	17
5–40–8	4	24	6	20	17–30–8	3	27	5	40
5–50–8	4	35	6	69					
					20–20–8	3	35	4	51
					20–30–8	3	2	4	47
					20–40–8	2	54	4	39
					20–50–8	2	54	4	53

Compressive Strength

DESCRIPTION OF TESTS

The compressive strength of the mortar was determined at 7 and 28 days by tests of 2-inch cubes made with mixtures gauged to the standard consistency represented by 65 to 80 per cent flow. The test specimens were prepared and cured in accordance with the methods specified for masonry cements in A.S.T.M. C 91-38T. The procedure is briefly described as follows:

The standard 2-inch cubes are formed in metal molds, stored in the molds for 48 to 52 hours in a damp closet at 70± 3°F. and 90 per cent relative humidity, removed from the molds and left in the damp closet until seven days have elapsed from the time of molding. Specimens to be tested after 28 days or longer are then immersed in clean running water until time for testing. Compression tests of the 7-day specimens are made immediately after removal from the damp closet. The 28-day cubes and those for longer periods are tested upon removal from the storage water.

Six cubes of each mortar were tested for each curing period, and the compressive strength was taken as the average of these tests. In only a few cases one or two of the cubes gave results which varied more than 15 per cent from the mean. These were discarded. Four or more individual cubes were used to determine the average strength.

Compressive strength was determined for mixtures containing 20, 30, 40 and 50 per cent 8-mesh clay in the cement-clay portion of the 1:3 mortar. Tests were also made with most of the clay samples on mortars in which more finely ground clay, passing 80-mesh, was used. A few of the clays were also ground to pass 100-mesh.

Table 14.—Water Requirement and Strength of Mortars

Sample No.	% water content of mortar for 65–80% flow. % clay replacing cement				Compressive strength at 7 days p.s.i. % clay replacing cement				Compressive strength at 28 days p.s.i. % clay replacing cement			
	20	30	40	50	20	30	40	50	20	30	40	50
8-mesh												
Shale												
0	14.5	15.2	15.8	16.4	1882	1502	1086	752	2665	2133	1552	1036
4	14.4	14.8	15.3	16.0	2369	1754	1346	831	3007	2199	1823	1227
5	15.0	15.4	16.3	17.2	2272	1765	1299	888	2900	2399	1700	1170
6	14.8	15.3	16.0	16.9	2401	1845	1223	741	3213	2361	1673	1039
7	15.0	15.2	15.5	15.7	2271	1734	1384	967	2877	2422	1881	1144
8	14.7	15.2	15.7	16.2	2423	1837	1409	972	3304	2694	1794	1304
17	15.0	15.5	16.1	16.6	2474	1696	1146	707	3017	2210	1577	967
18	14.5	14.9	15.3	15.7	2027	1556	1113	782	2822	2279	1603	1108
20	15.0	15.5	16.2	17.1	2149	1577	1046	675	2469	1988	1273	842
Underclay												
1	14.5	15.0	15.4	15.9	1801	1428	1038	713	2575	2089	1528	1054
11	14.0	14.5	14.9	15.3	1711	1431	1076	746	2635	1966	1485	1042
14	14.0	14.5	15.0	15.5	2335	1871	1269	856	3334	2597	1922	1228
Glacial till												
2	14.5	14.9	15.3	15.7	2224	1727	1262	892	3099	2306	1745	1245
3	15.0	15.5	16.2	17.0	2217	1738	1153	718	2785	2195	1541	989
12	14.3	14.7	15.1	15.6	2235	1780	1281	871	2884	2454	1694	1168
16	14.5	14.9	15.3	15.7	2036	1544	1146	801	2855	2213	1542	1124
Miscellaneous												
9	19.0	21.3	23.3	25.3	1316	772	490	299	1972	1305	853	646
10	15.0	17.0	18.0	19.0	2014	1508	985	659	2618	1850	1186	714
13	15.5	16.2	17.5	18.9	2117	1673	1052	625	2918	2231	1443	887
19	13.9	14.1	14.4	14.6	1840	1383	984	655	2749	2184	1710	1162
15	13.9	14.4	14.8	15.1	1911	1640	1135	758	2847	2322	1761	1119
Lime	13.5	14.3	14.7	15.1	2246	1865	1376	1010	3215	2703	1983	1332

TABLE 14.—(Concluded)

Sample No.	% water content of mortar for 65–80% flow. % clay replacing cement				Compressive strength at 7 days p.s.i. % clay replacing cement				Compressive strength at 28 days p.s.i. % clay replacing cement			
	20	30	40	50	20	30	40	50	20	30	40	50
80-mesh												
Shale												
0	14.5	15.0	15.5	16.1	2160	1802	1217	797	2828	2139	1553	1006
4	14.1	14.5	15.0	15.5	2286	1739	1292	854	2970	2167	1739	1093
5	15.0	15.9	16.6	17.4	1892	1469	1034	654	2560	2035	1320	858
6	14.8	15.3	16.0	16.7	2118	1651	1186	750	2826	2182	1467	844
7	14.8	15.2	15.5	15.9	2057	1658	1222	758	2707	2169	1645	998
8	14.2	14.7	15.1	15.5	2271	1862	1397	847	2669	2046	1499	962
17	14.6	14.9	15.4	16.0	2242	1912	1326	890	3062	2528	1811	1199
18	14.4	14.8	15.3	15.8								
20	14.8	15.3	16.1	17.1	1787	1554	1038	601	2565	2086	1559	879
Underclay												
11	15.7	16.1	16.6	17.2	1430	1063	966	695	1963	1578	1268	1010
14	14.2	14.7	15.1	15.4	2303	1789	1210	1090	2928	2340	1639	1386
Glacial till												
3	15.0	15.5	16.4	17.3	2363	1914	1268	737	3129	2374	1603	1044
Miscellaneous												
13	15.7	17.0	18.5	19.8								
100-mesh												
Shale												
6	14.8	15.3	16.0	16.8	2289	1788	1161	805	2796	2132	1442	954
Underclay												
14	14.5	15.1	15.4	15.9	2613	1803	1403	872	2960	2216	1758	1164
Miscellaneous												
15	13.5	13.5	13.5	13.6	2362	1856	1437	1087	3016	2467	1977	1490

RESULTS

Results of the strength tests are shown for the various mortars in table 14 together with the amount of water required for standard consistency. The relationship of the compressive strength to the amount of clay used in the mortar is shown for each material by curves in figure 6.

The foregoing data are summarized in table 15 and are to be compared with the following values for straight Portland cement and masonry cement mortars.

	Portland cement-mortar	Masonry cement-mortar
Per cent water content for 65–80 per cent flow	12.0	13.7
Compressive strength at 7 days, p.s.i.	2301	1052
Compressive strength at 28 days, p.s.i.	3105	1310

CONCLUSIONS

(a) A general linear relationship between the compressive strength at 7 days and that at 28 days for all of the mortar tested is shown in figure 6. This indicates that the clay and shale material in the quantities used does not prevent the progress of hydraulic setting of the cement.

(b) The average strengths of mortars containing 8-mesh shales or glacial tills are quite similar at comparable clay or shale contents at equal ages. A greater range of strength values is shown by the shales. This is undoubtedly due not only to the greater number of samples but to the wider range of properties of the shales with respect to clay mineral content, particle-size distribution, and slaking characteristics.

(c) Two of the underclays added as 8-mesh material gave consistently lower mortar strengths than did most of the shales and glacial tills, but one underclay gave

Table 15.—Summary of Data on Compressive Strength

Mortars containing	Compressive strength at 7 days, p.s.i				Compressive strength at 28 days, p.s.i.			
	30 per cent clay[a]		40 per cent clay[a]		30 per cent clay[a]		40 per cent clay[a]	
	Range	Average	Range	Average	Range	Average	Range	Average
Shales (8-mesh; 9 samples)	1502–1845	1696	1046–1409	1228	1988–2694	2298	1273–1881	1608
Underclays (8-mesh; 3 samples)	1428–1871	1577	1038–1296	1128	1966–2597	2217	1485–1922	1645
Glacial tills (8-mesh; 4 samples)	1544–1780	1697	1146–1281	1211	2195–2454	2292	1541–1745	1631
Shales (80-mesh; 8 samples)	1469–1912	1706	1034–1397	1214	2035–2528	2169	1320–1811	1574
Lime (1 sample)	....	1865	....	1376	....	2703	....	1983

[a] Indicates per cent of clay or shale in clay-cement or shale-cement portion of the mortars. For lime mortars indicates per cent of lime in lime-cement portion of mortar.

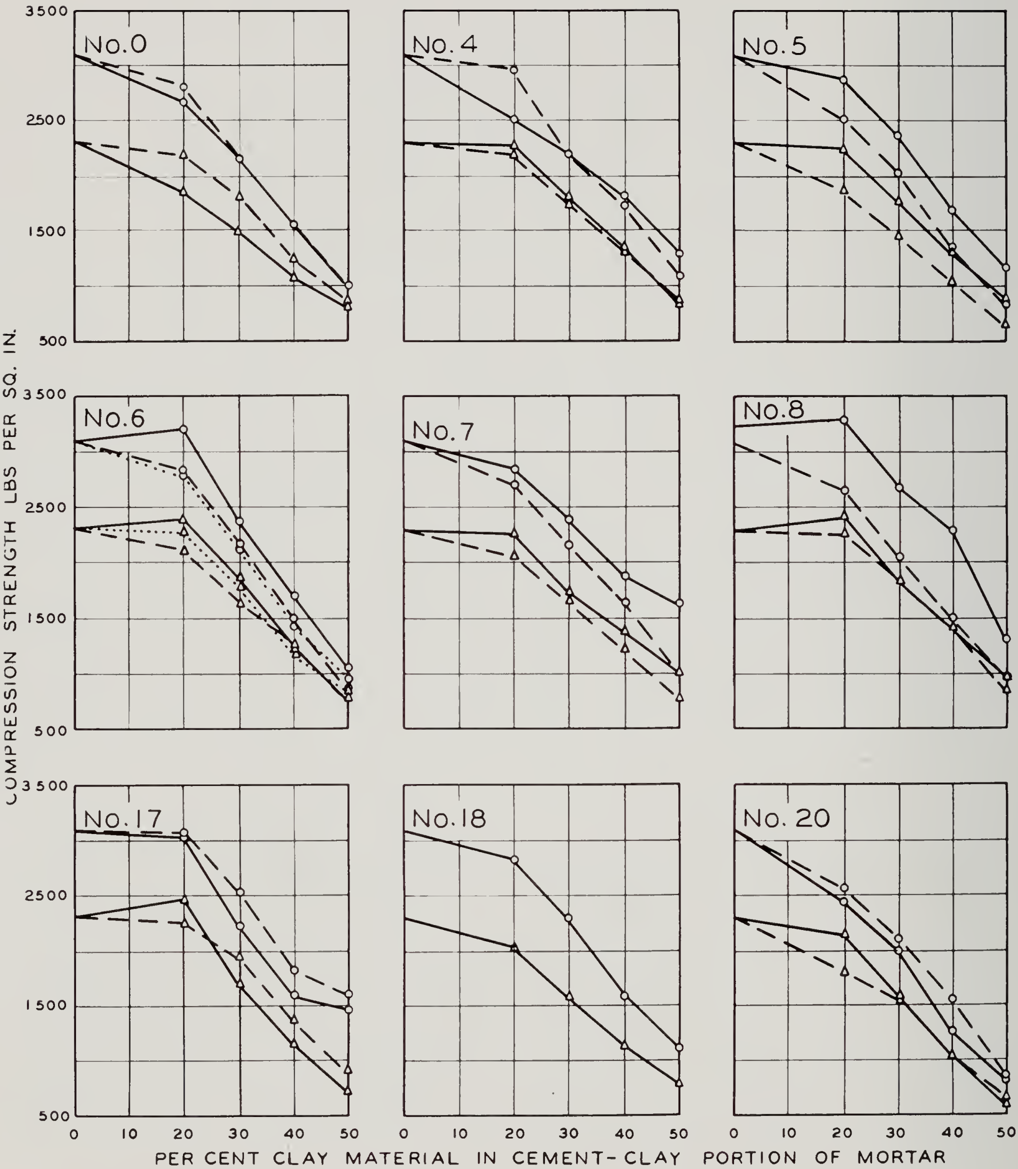

Fig. 5a.—Compressive strength of mortars containing shale at 7 and 28 days.

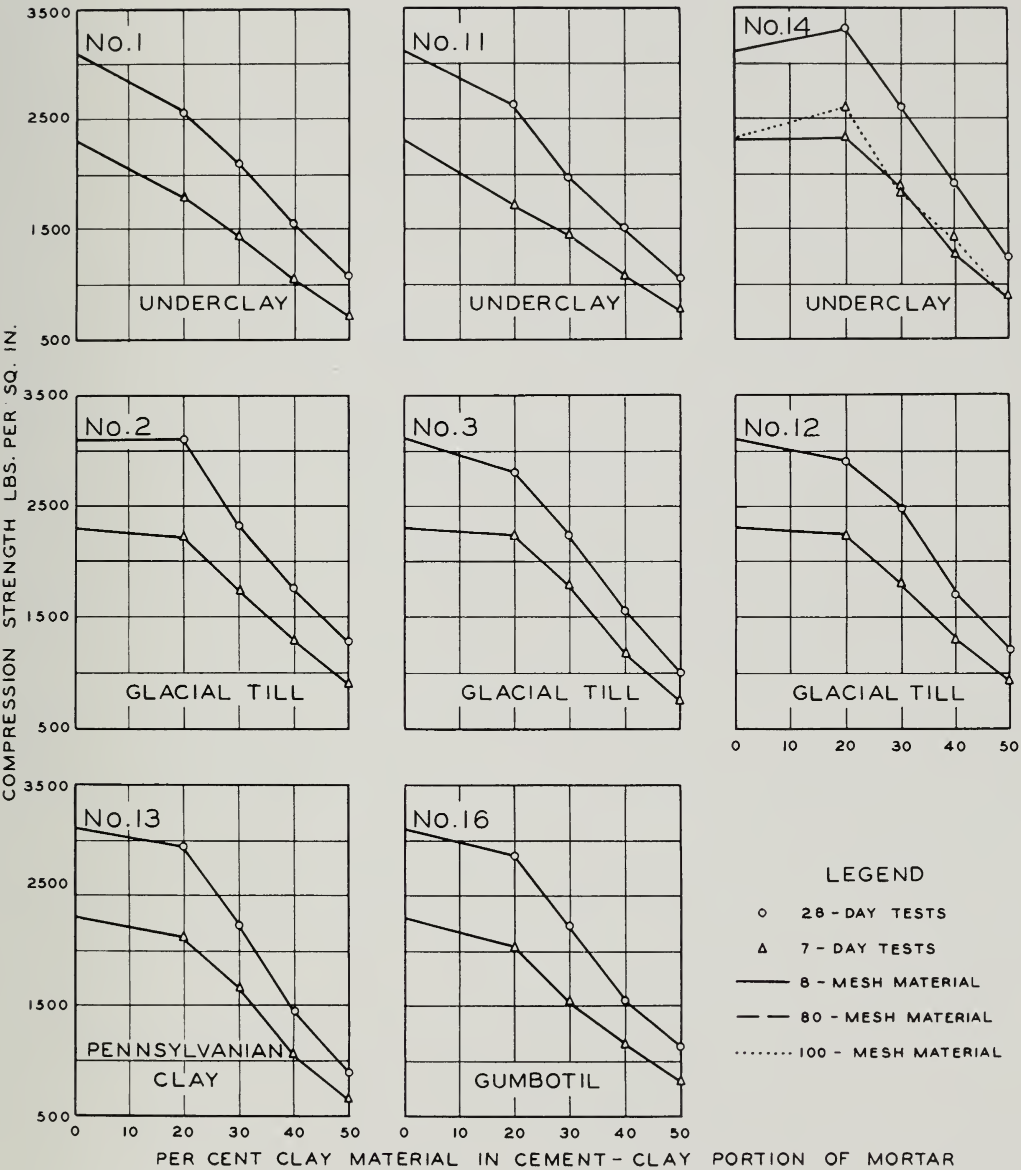

Fig. 5b.—Compressive strength of mortars containing clay or shale at 7 and 28 days.

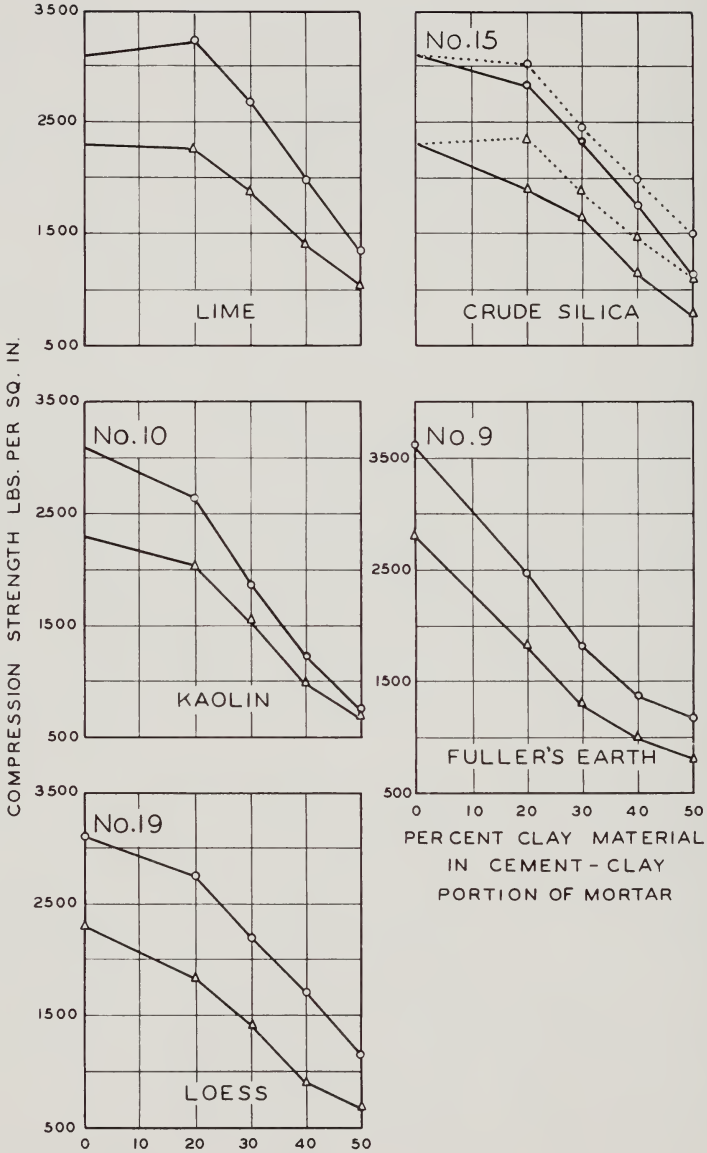

FIG. 5c.—Compressive strength of mortars containing clay or shale at 7 and 28 days.

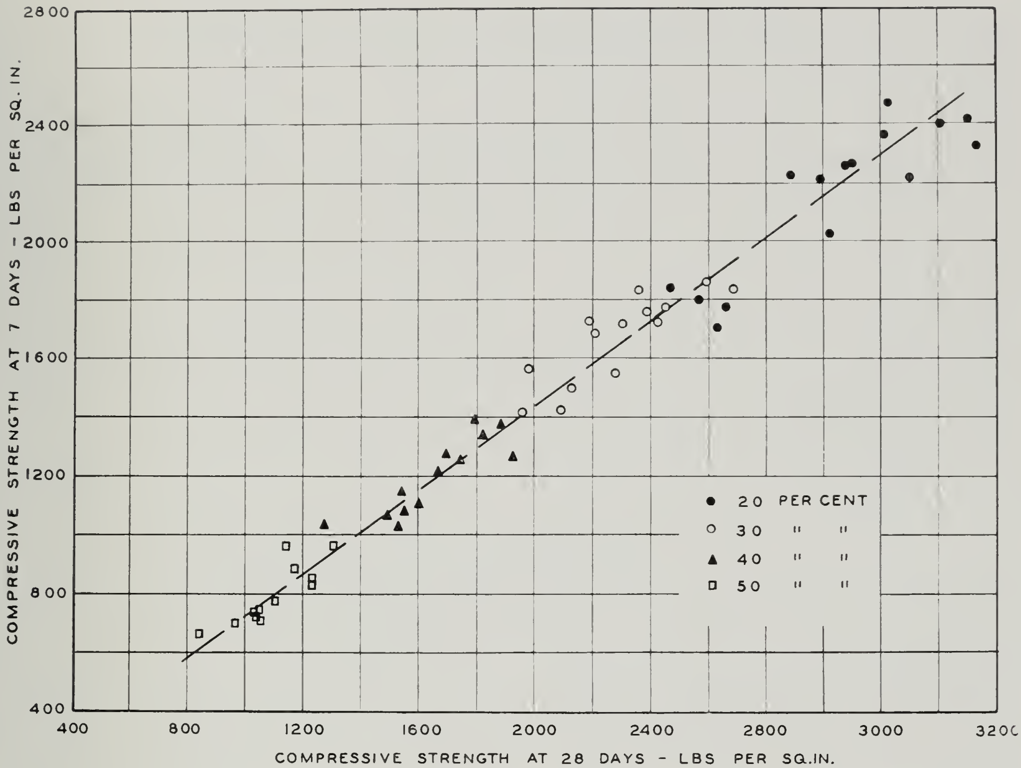

Fig. 6.—Comparison of 7-day and 28-day strength of mortars.

generally higher strength. The limited number of samples does not permit comparison of the characteristics of underclays as a group with those of shales and glacial tills.

(d) The finer grinding of the shales and other samples to pass 80 or 100-mesh had little effect on the strength of the mortars as compared with the result from the 8-mesh grind.

(e) Lime mortars show generally somewhat higher strength than do the mortars containing equal amounts of the clay materials, especially in the 28-day test. If, however, comparison is made between mortars having water retention values of 65 per cent, those containing shale or glacial till would be superior in strength to the lime mortar. This is indicated by the table 16 data on the averages of the materials from tables 11 and 15.

(f) Mortar containing most of the samples of shale or clay in amounts up to 40 per cent of the clay-cement portion showed greater strength than did the sample of commercial masonry cement mortar.

(g) The miscellaneous samples gave variable results. Sample 9, fuller's earth, gave consistently lower values than any other samples tested. Sample 15, crude southern Illinois tripoli containing only 5 per cent clay, gave slightly lower strength at 7 days than the averages for the mortar containing 30 or 40 per cent shale, underclay, or till. At 28 days, however, it gave a higher strength than the average. Grinding to 100-mesh increased the strength of the mortars containing the tripoli from 150 to 450 p.s.i.

Table 16.—Average Compressive Strength of Mortars
Containing the amount of plasticizer necessary to give 65 per cent flow in the water retention test.

Kind of Material	Per cent of material in clay-cement portion of mortar required for 65 per cent flow in water retention test	Average compressive strength of mortars containing the required percentage of clay material		
			7 days	28 days
Shales (Av.)	40	(40%)	1228	1608
Glacial tills (Av.)	32	(30%)	1697	2292
Lime (1 sample)	52	(50%)	1010	1332
Masonry mortar (1 sample)	..	....	1052	1310

Table 17.—Compressive Strength of Mortars after Aging and Weathering

Mortar Mixture	Compressive strength in lb. per sq. in.					
	7 days	28 days	6 months		16 months	Weathered 6 months
			Lot 1	Lot 2		
3-30-8	1738	2195	2528	2118	3188	2142
3-30-80	1914	2374	2441	....	2859	2134
5-30-8	1765	2399	1957	2123	2291	2018
5-30-80	1469	2035	2230	....	2558	2040
7-30-8	1734	2242	2015	2123	2339	1918
7-30-80	1658	2169	1906	....	2181	2079

Table 18.—Bond Strength of Mortar Joints in Tension

Sample No.	Per cent clay in cement-clay portion of batch	Per cent water in mortar	Grade of brick	Average per cent absorption of brick	Ultimate tensile strength of mortar joint p.s.i.
Shale					
6	30	17.5	Soft	8.2	39
6	30	17.5	Medium	2.0	37
6	30	17.5	Hard	1.2	40
Underclay					
12	30	16.7	Soft	8.2	38
12	30	16.7	Medium	2.0	57
12	30	16.7	Hard	1.2	47

Aging and Weathering Tests of Mortars

DESCRIPTION OF TESTS

The effects of periods of curing under water for more than 28 days and the effects of weathering on the strength of typical clay-cement mortars was made on mixtures containing two shales and one glacial till. Mortar cubes from the 30-per cent clay mixture, in the proportions by weight of 30:70:300 (clay, cement, sand) were made with both the 8-mesh and the 80-mesh grinds of shales Nos. 5 and 7 and of the glacial till No. 3. These were cured in the normal manner, one day in the mold in the damp closet, followed by six days in the damp atmosphere after removal from the mold, and then storage under water. At the end of 28 days part of the cubes were placed out-of-doors on a platform and were subjected to normal atmospheric freezing and thawing, wetting and drying from January to June. They were then examined for evidence of cracking or disintegration and were saturated by immersion in water for 48 hours before testing for compressive strength. Other specimens were kept indoors and remained in storage under water for periods of six and 16 months before testing. As a check on the results, another set of specimens was made by a different operator about 11 months after the first was made. These were tested for compressive strength after six months' storage under water.

RESULTS

The results of tests are shown in table 17 and represent the average of six to eight specimens in each case. The mortars made with both coarsely and finely ground shale No. 5 and glacial till No. 3 showed a very decided progressive gain in strength throughout the period of storage under water, but the mortars made with shale No. 7 appeared to reach their maximum strength at 28 days. The subsequent changes in strength of these latter mixtures is not significant since they do not exceed normal variation in results of individual test specimens of mortars in compression. This is indicated by comparative results of the check tests made at the six-month period.

At the end of the six months' period of weathering there was a little evidence of checking on the top surfaces of the mortar cubes made with the glacial till but none on the specimens made with either shale. No other signs of cracking and no disintegration could be detected. There was no significant change in strength of the mortars as compared with the results of the storage under water for an equal period of time.

CONCLUSIONS

It may be assumed from the foregoing that the clay-cement mortars will maintain adequate strength under natural weathering conditions and will not be inferior in weather resistance to mortars containing equivalent amounts of lime hydrate as a plasticizer. This has been confirmed by results of freezing and thawing tests in other investigations to which reference has been made.

It is likewise evident that for the three shale and clay samples studied, grinding to 80-mesh produced no change of practical significance in the compressive strength of the mortars containing them as compared to mortars containing the same samples ground to 8-mesh.

Bond Strength of Mortar Joint

DESCRIPTION OF TESTS

The bonding strength of the mortar joint between brick was tested in tension with mortars made with 30 per cent replacement of cement by a typical shale and an underclay, samples Nos. 6 and 12, respectively. For this test, the coarsely ground 8-mesh clay materials were used.

Side-cut shale brick of three different degrees of porosity and designated by the manufacturer as soft-, medium-, and hard-burned were carefully selected for uniformity in each grade. The test specimen consisted of two brick set on the flat, one above the other and at right angles, with a one-half inch mortar joint between them. These were prepared with the use of a jig which regulated the thickness of the mortar joint and insured the parallelism of the brick surfaces in forming the joint. Mortar of normal consistency, 100 to 115 per cent flow, was spread on the surface of the lower brick and the upper brick was pressed down on the mortar bed until the ends rested on sills of proper height to give the required thickness of the mortar joint. The excess mortar along the edges of the brick was

trimmed away with a trowel, leaving a mortar joint approximately 3¾ x 3¾ inches in area. The mortar was applied to the dry brick in making the test specimens. These were allowed to stand in the open air until the mortar hardened and were then stored in a damp chamber for 28 days.

At the end of this period the specimens were tested, without drying. The assembly was suspended by resting the ends of the upper on steel supports and tension was applied to the joint by applying a downward pressure on the ends of the lower brick through steel extensions from the head of the testing machine. Care was taken to avoid eccentricity in applying the load. Six specimens were tested for each mortar and grade of brick.

RESULTS

The average results of each group of specimens are given in table 18. These bond strengths compare favorably with data reported for mortars of types commonly used for masonry construction. It may therefore be concluded that clays and shales may be used in amounts which will provide suitable workability in mortars which have satisfactory bonding strength with masonry units.

Plasticity and Workability of Mortars

Observations concerning the plasticity and workability of the mortars were made during the preparation of the various mortars for use in water retention tests. The comparative ratings listed in table 19 are based on the texture as determined by feel in mixing and on the behavior of the mortar in trowelling.

Table 19.—Rating as to Plasticity and Workability of Mortar Containing the Sample Used

Sample No.	Plasticity and workability of mortar containing 8-mesh grind	Plasticity and workability of mortar containing 80-mesh grind
Shale		
0	Fair	Good
4	Good	Good
5	Good	Good
6	Good	Good
7	Fair	Fair
8	Poor	Poor
17	Good	Good
18	Poor	Poor
20	Good	Good
Underclay		
1	Fair	Fair
11	Poor	Fair
14	Poor	Poor
Glacial till		
2	Good	Good
3	Good	Good
12	Fair	
16	Fair	
Miscellaneous		
9	Too plastic—sticky	Too plastic—sticky
10	Too plastic—sticky	....
13	Good	Good
14	Poor	....
15	Poor	....

Influence of Characteristics of Clay and Shale Plasticizers Tested on Properties of Mortars

The variety of clays and shales studied and the detailed data presented regarding the kind and amount of clay mineral they contain, their ultimate particle size, the particle size of the ground materials as used in the mortars, and the information on slaking in water affords a favorable opportunity to determine the relationship, if any, between these characteristics of clays and shales and the properties of mortars containing them as plasticizers. It is proposed first to compare certain of the characteristics of the clays and shales with each other and then to examine the data regarding the plasticizers with reference to the results of the tests on the mortars.

MINERALOGICAL AND MECHANICAL COMPOSITION OF CLAYS AND SHALES AND SLAKING CHARACTERISTICS

The data in tables 3, 6 and 8 may be summarized as shown in table 20.

The given data fail to show any correlation between the various properties of the clay and shale samples as groups and their slaking characteristics. In all probability the degree of induration of the samples tested has a greater effect on the slaking than does the ultimate particle size, percentage of clay mineral or the particle-size distribution of the 8-mesh grind. As the

TABLE 20.—SUMMARY OF DATA ON ULTIMATE PARTICLE SIZE, AMOUNT OF CLAY MINERAL, AND SLAKING TESTS

	Slaking test per cent minus 200-mesh		Ultimate particle size—per cent				Per cent clay mineral		Particle size, 8-mesh ground clay, per cent minus 200-mesh	
			Minus 10-microns		Minus 270-mesh					
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
Shales	46–89	75	46–86	60	84–99	93	45–85	66	24–59	38
Underclays	75–82	79	59–78	67	74–97	89	60–70	63	26–33	29
Tills	84–90	88	48–75	61	74–94	85	40–60	46	21–50	31
Miscellaneous[a]	72–98	88	34–94	76	99–100	99	20–95	70	15–64	29

[a] Excluding sample 15 which contains only 5 per cent clay mineral material.

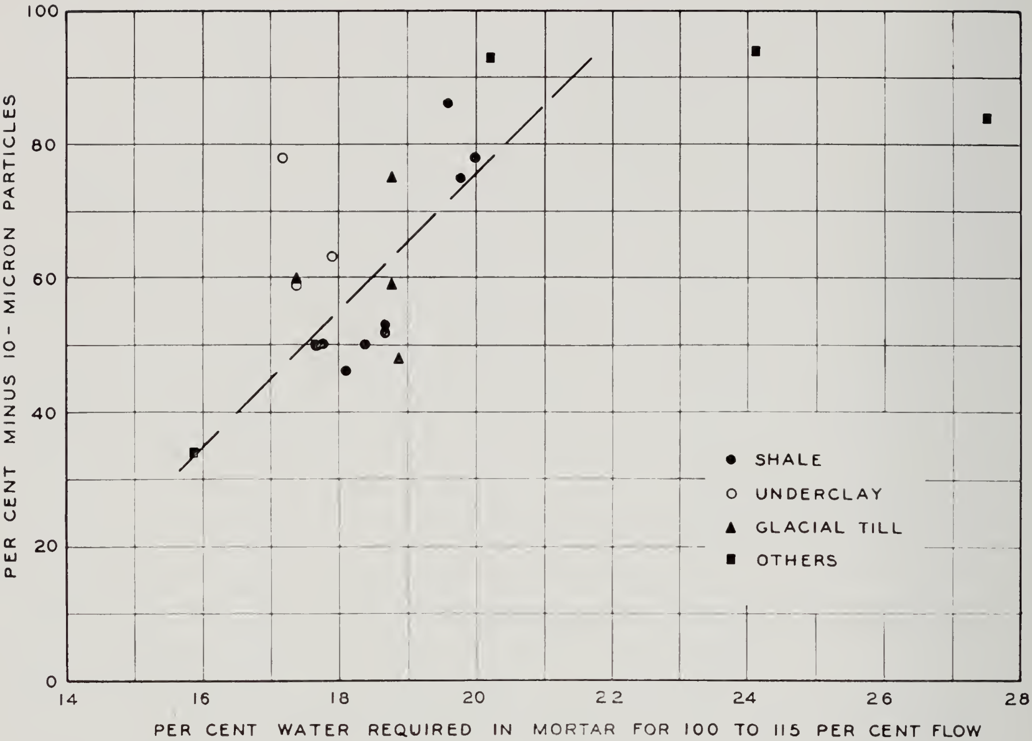

FIG. 7.—Relation between the amount of minus 10-micron particles in clay material and the water requirement of mortar for standard consistency of 100 to 115 per cent flow with 50 per cent clay in the cement-clay portion.

shales and underclays are part of the bedrock of Illinois they might be expected to be somewhat more indurated than the tills and miscellaneous samples which (with one exception) are not bedrock clays, and this difference is evident in the average data for the various groups of clay materials.

CHARACTERISTICS OF CLAY AND SHALE PLASTICIZERS AND WATER REQUIRED FOR STANDARD CONSISTENCY OF MORTAR

Examination of the data regarding the clay and shale plasticizers show no clear-cut relationship between the properties of these materials and the amount of water required for standard consistency of the mortars. Any relationship that might exist would be somewhat obscured by the relatively small proportion of the clay material in the mortar. Even with a substitution of 50 per cent of clay for cement, the amount used is only one-eighth of the total weight of the batch. There is, however, a strong indication that the water requirement of the mortar is roughly a function of the proportion of fine particles in the clay material. This is shown in the comparison of the percentage of water used in the mortars with the fraction of minus 10-micron particles in the clay in figure 7. Some of the samples show considerable discrepancies from a linear proportionality, but the trend is clearly indicated.

CHARACTERISTICS OF CLAY AND SHALE PLASTICIZERS IN RELATION TO WATER RETENTION

The water retention of a mortar that contains a clay or shale plasticizer might be expected to bear a relationship to the amount of clay mineral and to the proportion of very fine particles in the material. The wetting of the extensive area of surface exposed by the fine-grained material and the tenacity with which the water film is retained contribute to the water retentivity of the mortar. Furthermore, the mixture of the fine particles with the coarser grains of the sand causes the particles to be closely packed and reduces the permea-

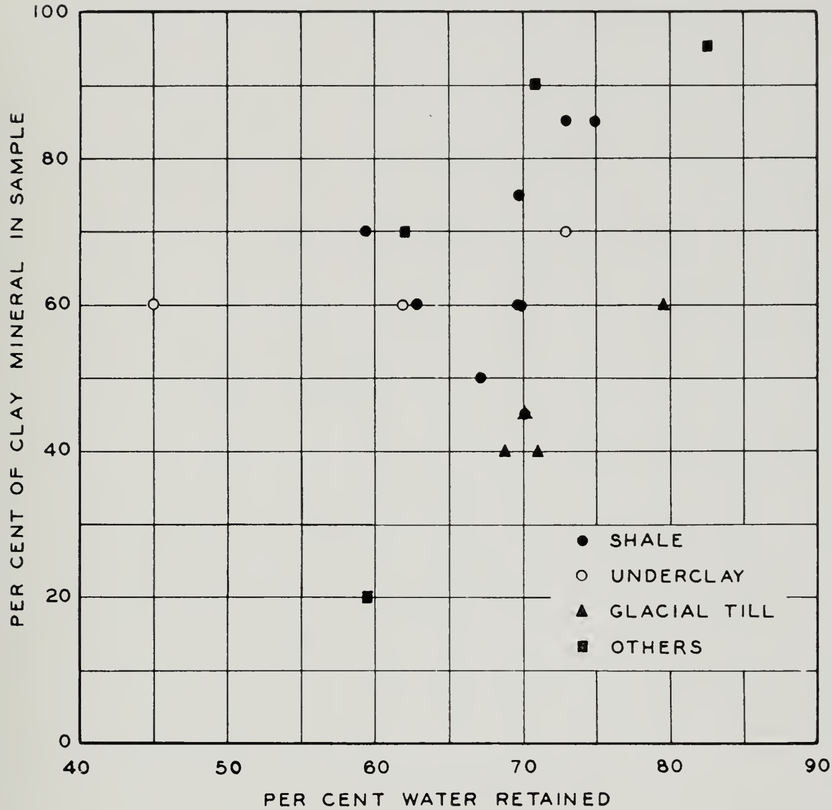

Fig. 8.—Relation between the amount of clay mineral in the sample and the water retention of mortar containing 50 per cent of clay in the cement-clay portion.

bility, thus hindering movement of water out of the mass. Both effects depend in part on the ease with which a clay or shale can be dispersed in water. An idea of this property is furnished by the slaking test.

No clear relationship between the amount of clay mineral in the plasticizer and the water retention of the mortar in which it is used is shown in figure 8, but figure 9 indicates that increased values of water retention are obtained with clay materials having a large proportion of fine particles. The general trend is evident although some of the samples are distinct exceptions.

The data presented in figure 10 show that slaking of the coarse particles of the 8-mesh clay material proceeds to a considerable degree in the mortar mixing operation. The degree of correlation between the amount of minus 200-mesh clay material resulting from the slaking test and the water retention of the mortar is closely similar to that shown in figure 9 for the minus 10-micron material from the ultimate particle-size determination.

CHARACTERISTICS OF CLAY AND SHALE PLASTICIZERS IN RELATION TO COMPRESSIVE STRENGTH

Correlations between the characteristics of the clay and shale plasticizers and the compressive strength of the mortars are not well defined. There is some indication that large amounts of clay mineral tend to give low compressive strength and also that clays in which kaolinite and montmorillonite predominate are less favorable for producing mortars of high strength than are the clays or shales which contain illite as the principal clay mineral. That large amounts of fine particles in the clay material reduce the strength of the mortar is indicated by the trend of the data in figure 11. The relationship is even more clearly defined in a comparison of compressive

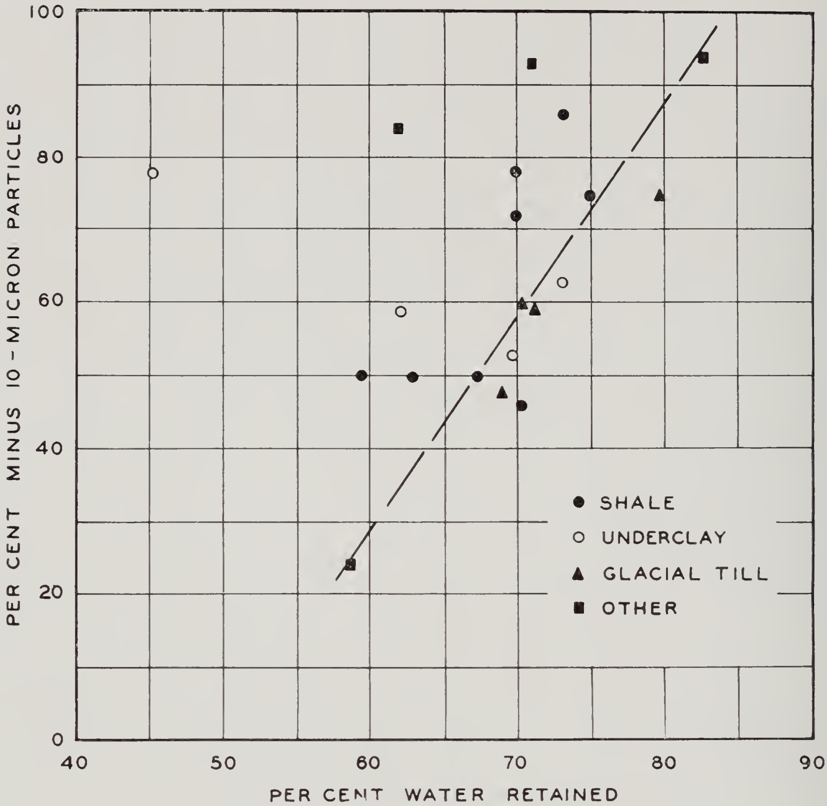

Fig. 9.—Relation between the amount of minus 10-micron particles and the water retention of mortars containing 50 per cent clay in the cement-clay portion.

strength with the percentage of minus 4-micron particles in the clay or shale, figure 12. These trends are obscured in the mortar mixtures containing smaller amounts of the clay material, as might be expected, because of the comparatively small ratio of the clay to the total material in the batch.

CHARACTERISTICS OF CLAY AND SHALE PLASTICIZERS IN RELATION TO COMPRESSIVE STRENGTH AFTER AGING AND WEATHERING OF MORTARS AND BOND STRENGTH OF MORTAR JOINTS

The amount of data on compressive strength after aging and weathering and bond strength of mortar joints is too limited to permit generalizations regarding the relation of such data to the characteristics of the clay and shale plasticizers. No correlation is evident between the strength data at hand and the information regarding the plasticizers.

CHARACTERISTICS OF CLAY AND SHALE PLASTICIZERS AND WORKABILITY OF MORTARS

Mortars having fair to good working properties resulted from all the shale samples excepting numbers 8 and 18 which had 54 per cent and 47 per cent of material retained on the 200-mesh sieve in the slaking tests. Samples Nos. 5 and 20 containing respectively 33 per cent and 27 per cent plus 200-mesh material gave good working properties. This suggests that shale plasticizers may contain considerable amounts of sand and yet give mortars having good working properties. However, it appears that as much as 45 to 50 per cent of sand will cause poor workability.

The underclay, till, and miscellaneous samples all have over 70 per cent through 200-mesh in the slaking tests and all the mortars containing them had fair to good plasticity excepting the mortar containing sample No. 19, loess. The fact that this

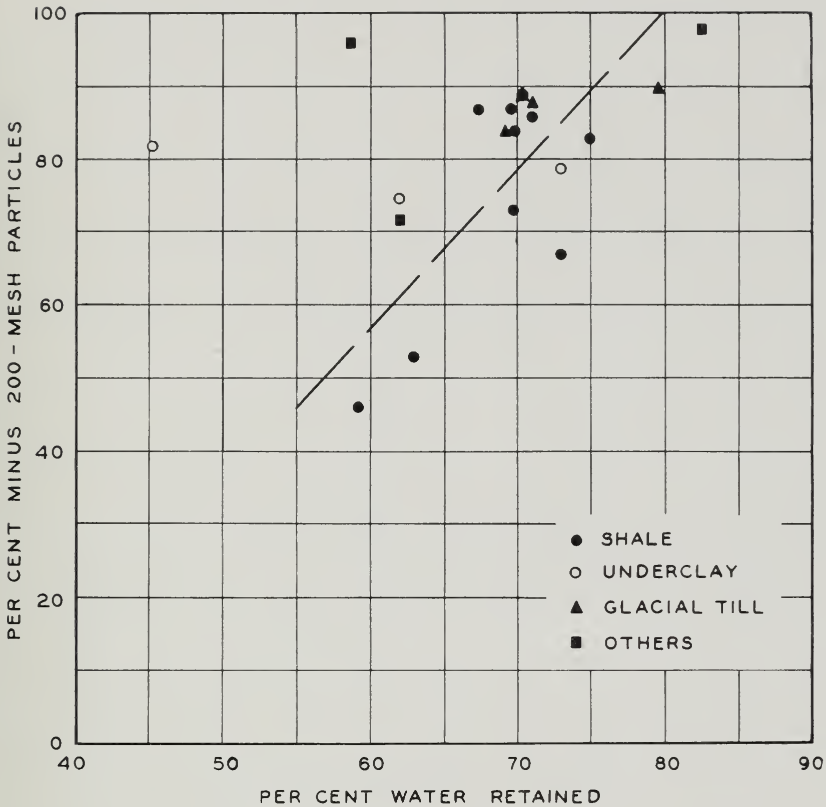

Fig. 10.—Relation between the amount of minus 200-mesh particles from slaking test and the water retention of mortars containing 50 per cent clay in the cement-clay portion.

sample has a low clay content and is largely silt probably accounts for its poor plasticity.

No correlation is evident between workability and amount or character of the clay mineral material present in the plasticizers.

Importance of Clay Mineral Materials in Mortar Mix

In order to obtain an idea of the importance of clay mineral materials in mortar mix a sample of tripoli or "amorphous silica," No. 15, containing only 5 per cent of clay mineral was included in the study. Another sample, No. 19, a wind deposited clayey silt known as loess, contained only 20 per cent clay mineral material, the rest being largely quartz silt. It is of interest to compare the results of tests on these with the other more clayey shale, underclay, and till samples tested when ground to 8-mesh. These latter are subsequently referred to in this discussion as the "clay samples" and the mortars containing them as "clay mortars."

Water required for 100-115 per cent flow.—The tripoli and loess mortars commonly required 1 to 2 per cent less water than the clay mortars.

Water retention, per cent of original flow.—The water retention of the tripoli mortar was ¼ to ½ that of the clay mortars. Retention of the loess mortar was less than most of the clay mortars but closely approached some. It exceeded the retention of one underclay mortar.

Compressive strength.—The compressive strength at seven days of mortars containing 30 per cent tripoli in the tripoli-cement portion of the mortar is within the range of strengths given by the clay mortars. The same applies to mortars containing 40 per

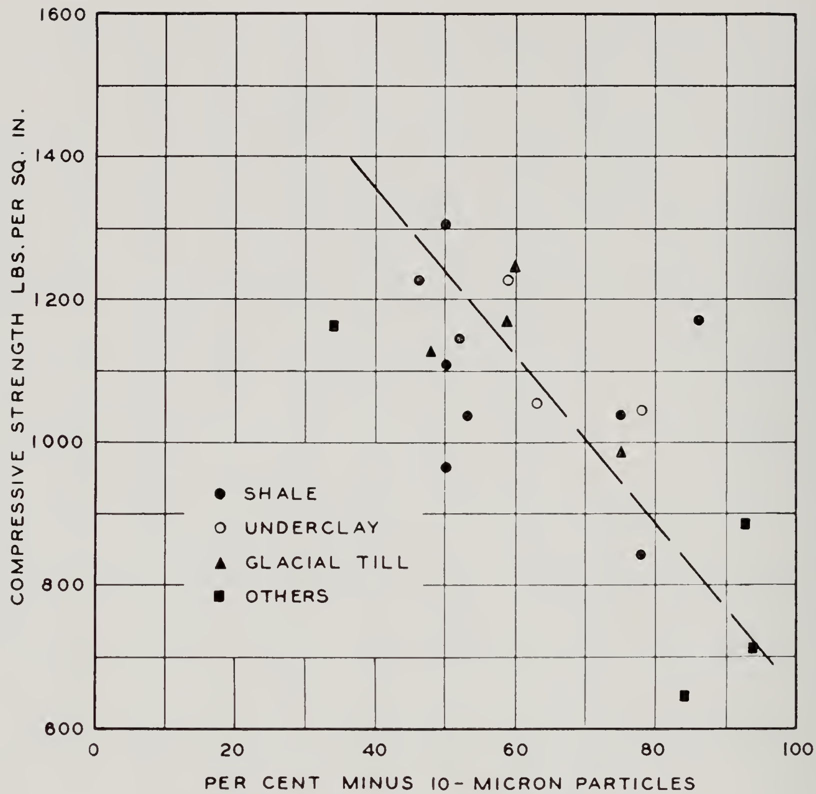

FIG. 11.—Relation between the amount of minus 10-micron particles and the 28-day compressive strength of mortars containing 50 per cent of clay in the cement-clay portion.

cent tripoli. In 28-day strength tests the tripoli mortar compared favorably with many of the clay mortars.

The mortar containing 30 per cent or 40 per cent loess gave lower strength values than the clay mortars at 7 days, but at 28 days the 30 per cent loess had a mortar strength somewhat low but better than some of the clay mortars. At 40 per cent loess, 28 days, the loess mortar had greater strength than many of the clay mortars.

Workability of mortars.—The mortars made with tripoli or loess had poor workability and plasticity.

Conclusions.—From the foregoing it seems likely that mortars containing clay or shale mortar mix owe their water retention and workability to the clay mineral present in the clay or shale. Compressive strength and water required for 100 to 115 per cent flow appear to be largely independent of clay mineral material. It may well be that in so far as mortar strength is concerned the mortar mix serves chiefly as a fine aggregate which imparts strength by filling the pores between the mortar sand grains with finer grains of quartz.

Requirements for Masonry Mortar

Specification requirements for masonry cements and mortars vary considerably with the type of use of the mortar and with the conditions of exposure to which it will be subjected. For reinforced masonry construction, mortars of higher strength than those suitable for ordinary brick work are required. The Federal Specification SS-C-181b provides for two types of mortar, based on the conditions of use. Type I is intended for use when not exposed to frost action, both in solid masonry and in non-load-bearing masonry of hollow units. Type II is intended for general use. The following requirements are specified:

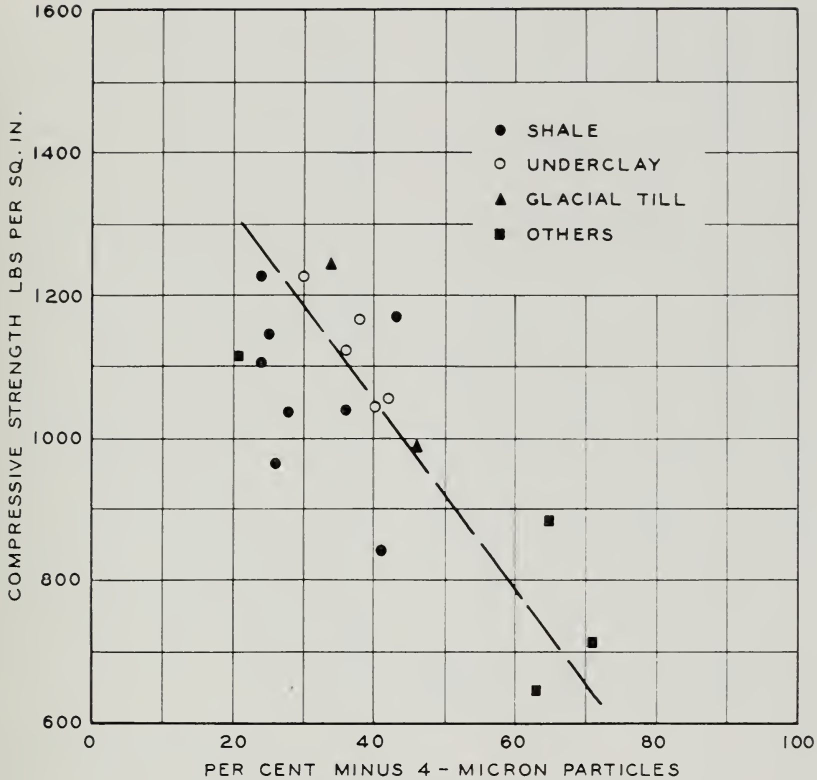

FIG. 12.—Relation between the amount of minus 4-micron particles and the 28-day compressive strength of mortars containing 50 per cent clay in the cement-clay portion.

Fineness.—The residue on a 200-mesh sieve, when the wetted material is washed by a stream of water until no more passes through the screen, shall not exceed 12 per cent by weight.

Time of setting.—Minimum by the Gilmore needle method, 60 minutes; maximum for Type I, 48 hours, for Type II, 60 hours.

Soundness.—Pats stored in air at 60-70 per cent relative humidity and 70 deg. F. shall show no distortion, disintegration, or cracking after periods of seven and 28 days.

Strength. — Minimum compressive strength of 2 in. cubes of 1 : 3 mortar, using standard Ottawa sand, at seven and 28 days, respectively, for Type I, 250 and 500 lb. per sq. in.; for Type II, 500 and 1000 lb. per sq. in.

Water retention.—The flow after suction shall be greater than 65 per cent.

In *Brick Engineering*, it is suggested, in connection with weather resistance, that the minimum strength at seven days should be 600 lbs. per sq. in. In specifications for lime-cement mortars, three classes and their requirements are designated.

The 1 : 1 : 6 mortar (cement, lime-putty, and sand by volume) (minimum compressive strength at seven days = 400 lbs. per sq. in.) is suitable for general use above grade and is recommended specifically for parapet walls, chimneys, and exterior walls subject to severe exposure, also for structural clay tile construction.

The 1 : 2 : 7–9 (cement, lime-putty, sand) mortars, having a minimum seven-day strength of 150 lbs. per sq. in., are suitable for non-load-bearing walls not subjected to severe exposures, also for load-bearing walls in which unit compressive stress is not excessive. The 1 : 1/4 : 2 1/2-3 mortar (cement, lime-putty, sand) with a minimum strength

of 1500 lbs. per sq. in. at seven days, is suitable for general use and is recommended specifically for reinforced brick masonry and for plain masonry below grade or in contact with earth, such as in foundations, retaining walls, walks, sewers, manholes, and catch basins.

In the building regulations for reinforced brick masonry,[17] the specification requires a compressive strength of 2-inch mortar cubes of 1500 lbs. per sq. in. at seven days and 2000 lbs. per sq. in. at 28 days.

In connection with water retention requirements the authors say, "Where high-strength mortars are required, as brick sewer construction or in reinforced brick masonry, particularly in contact with earth, it may be necessary to reduce this requirement for water retentivity. However, satisfactory mortars are available for most uses which have flow after suction of 65 per cent or more and this requirement should, as a rule, be included in the specification."

Other specifications for masonry mortars for general use require compressive strength of 1 : 3 mixtures at seven days of 175 to 700 lb. per sq. in.

Clay-Cement Mortars in Relation to Specification Requirements

Fineness.—Many of the Illinois clays and shales, even when coarsely ground, would slake sufficiently in the wet screening test to satisfy the Federal specification for fineness. A somewhat finer separation than the 8-mesh grind used for most of these tests would undoubtedly be desirable but it does not seem at all necessary to grind the dry clays to extreme fineness nor to use air separation methods to insure a satisfactory mortar-mix product. Only in the case of clays or shales that are difficult to slake or which develop little plasticity unless finely ground would the extreme grinding be essential. The many cases in which mortars have been made with comparatively coarse clay material and have resisted weather conditions and maintained strength over a long period of years indicates that the very fine grinding is not essential to good mortar properties.

Strength.—With the exception of the fuller's earth (9) any of the Illinois clays and shales included in this investigation can be used in amounts up to 40 per cent or more of the cement-clay portion in mortars which will meet the strength requirements of either type in the Federal specification. These samples are of such wide variety as to fairly represent the range of Illinois materials which might be considered or produced for mortar mix. It might, therefore, be reasonably stated that most of the shales, underclays, and glacial tills found in the State can be satisfactorily used in mortars that are suitable from the standpoint of strength for general masonry uses.

The results of the compressive strength tests also indicate that nearly all of these materials may be substituted for cement in amounts up to 30 per cent or more in high-strength mortars suitable for reinforced masonry construction. Nearly all of these clay-mix mortars were superior in strength to the commercial masonry mortar tested and compared very favorably with those containing the lime hydrate in the same proportions.

Water retention.—The clay materials that give mortars of high strength are not always satisfactory from the standpoint of water retentivity of the mortar. In table 11 the approximate proportion of the 8-mesh clay required in the mortar mixture to meet the requirement of 65 per cent flow after suction has been indicated. Some of the materials which provide good water retention properties in the mortar are not entirely desirable with respect to their effect on mortar strength. This is especially evident in the case of samples Nos. 10 and 13. On the other hand, shale sample No. 8 gave excellent mortar strength, but none of the mixtures showed sufficient plasticity or water retentivity. In this case, as in several others, finer grinding of the material would improve the values for water retention. The results with 80-mesh clay material as compared with those for the 8-mesh grind for some of the samples tested showed a gain of three to eight per cent in water retention. Finer grinding of the clay material is, therefore, definitely desirable in respect to this property of the mortar. Many of the mixtures which lacked in plasticity and workability could be improved by use of finer-ground clay material and would gain sufficiently in water retention value to meet the specification.

[17] Plummer, H. C., and Reardon, L. J., Brick Engineering; Structural Clay Products Institute, 1939.

Summary

The results of the investigation show that Illinois clays and shales with a wide range of mineralogical and physical characteristics can be satisfactorily used as mortar-mix materials. Highly plastic clays and those which contain a very large proportion of particles of near colloidal size are less suitable than the shales, underclays, and tills which are somewhat coarser in texture. The materials in which the clay mineral is principally kaolinite do not seem to be as satisfactory for the purpose as those in which illite predominates.

Clay additions in mortar serve to some extent as a fine aggregate, and the range of particle sizing is of importance in this respect, both from the standpoint of mortar strength and of water retention. The exact relationship of the gradation in particle sizing to the mortar properties is obscured by the effects of other factors.

Extremely fine grinding of clay materials for mortar mix is not essential in most cases because the clay particles generally slake sufficiently to produce a large proportion of fine-grained material. Fine grinding tends to lower the mortar strength but improves water retentivity.

Most of the clay materials may replace cement to the extent of 30 per cent or more by weight in 1:3 mortars which will have sufficient strength to meet requirements for use in ordinary masonry and for conditions of severe exposure. Most of the mortars of such proportions would also be suitable for reinforced masonry construction.

It has been shown by various tests and investigations that cement mortars containing clays as plasticizers are resistant to weathering and withstand freezing and thawing satisfactorily. In these and other respects such mortars are fully equal to those with lime hydrate or to the commercial masonry cements.

Illinois State Geological Survey
Report of Investigations No. 100
1944